PB87-140901

External Combustion Particulate Emissions Source Category Report

Acurex Corp., Mountain View, CA

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Nov 86

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/7-86/043	2.	3. RECIPIENT'S ACCESSION NO. PB87 140901/AS
4. TITLE AND SUBTITLE External Combustion Particulate Emissions: Source Category Report		5. REPORT DATE November 1986
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Donald Van Buren, David Barbe, and A. Walter Wyss		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Acurex Corporation P.O. Box 7044 Mountain View, California 94039		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3159, Task 12
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 6/84 - 7/86
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is Dale L. Harmon, Mail Drop 61, 919/541-2429.

16. ABSTRACT The report gives results of the development of particulate emission factors based on cutoff size for inhalable particles for external combustion sources. After a review of available information characterizing particulate emissions from external combustion sources, the data were summarized and rated in terms of reliability. Size specific emission factors were developed for these data for the major processes used in combustion. A detailed process description is presented with emphasis on factors affecting the generation of emissions. A replacement for Sections 1.1 (Bituminous and Subbituminous Coal Combustion), 1.2 (Anthracite Coal Combustion), 1.3 (Fuel Oil Combustion), 1.4 (Natural Gas Combustion), 1.6 (Wood Waste Combustion in Boilers), and 1.7 (Lignite Combustion) of AP-42 was prepared, containing the size specific emission factors developed under this program.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Fuel Oil	Pollution Control	13B
Combustion	Natural Gas	Stationary Sources	21B
Emission	Wood Wastes	External Combustion	14G 11L
Particles	Lignite	Particulate	
Aerosols		Emission Factors	07D
Coal			21D

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 203
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

PB87-140901

EPA/600/7-86/043
November 1986

EXTERNAL COMBUSTION PARTICULATE EMISSIONS: SOURCE CATEGORY REPORT

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EPA Contract 68-02-3159
Technical Directive No. 12

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REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

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ABSTRACT

The objective of this study was to develop particulate emission factors based on cutoff size for inhalable particles for external combustion sources. After review of available information characterizing particulate emissions from external combustion sources, the data were summarized and rated in terms of reliability. Size specific emission factors were developed from these data for the major processes used in combustion. A detailed process description was presented with emphasis on those factors affecting the generation of emissions. A replacement for Sections 1.1 (Bituminous and Subbitumous Coal Combustion), 1.2 (Anthracite Coal Combustion), 1.3 (Fuel Oil Combustion), 1.4 (Natural Gas Combustion), 1.6 (Wood Waste Combustion in Boilers), and 1.7 (Lignite Combustion) of AP-42 was prepared, containing the size specific emission factors developed under this program.

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SECTION 1

INTRODUCTION

This document is a source category report on inhalable particulate matter emitted by external combustion sources. Inhalable particulate matter can be characterized as particles of respirable size capable of reaching the lower lung.

The source category report summarizes available data on inhalable particulate emissions from typical source combustion units fired with coal, oil, natural gas, and wood wastes. The main objectives of this study are to:

- Develop reliable total and size-specific particulate emission factors for controlled and uncontrolled emissions for various external combustion sources

- Update Sections 1.1 "Bituminous Coal Combustion," 1.2 "Anthracite Coal Combustion," 1.3 "Fuel Oil Combustion," 1.4 "Natural Gas Combustion," 1.6 "Wood Waste Combustion in Boilers," and 1.7 "Lignite Combustion" in the document "Compilation of Air Pollutant Emission Factors," (AP-42) (Ref. 1) with the size-specific emission factors developed during this study

These objectives were met by an intensive review of EPA's Fine Particle Emission Information System (FPEIS) (Ref. 2 and 3 and see Appendix A, Glossary of Terms), a literature search, and personal contact with individuals and organizations known to be familiar with external combustion sources. The individuals and organizations are listed in Appendix B. Sources for data included:

- Regulatory agencies

    -- U. S. Environmental Protection Agency

    -- State and local air pollution control agencies

- Trade organizations

    -- American Petroleum Institute

    -- American Boiler Manufacturers Association

  - Chemical Manufacturers Association
  - Edison Electric Institute
  - Electric Power Research Institute
  - National Council of the Paper Industry for Air and Stream Improvement (NCASI)
- Industry contacts
- AP-42 external combustion sources background file at the Office of Air Quality Planning and Standards (OAQPS)
- EPA's FPEIS listings dated June 20-21, 1983 (Ref. 2) and September 19, 1983 (Ref. 3)

Particle sizes are usually expressed in terms of the aerodynamic equivalent diameter (see Glossary of Terms). This method of size expression is useful because it is readily determined through straightforward measurement where the other properties of actual particle size and density may not be obtainable. A particle's inertial characteristics can be used to best predict where deposition will occur in the respiratory system, and actual particle size and density may not be obtainable.

There are two general classifications of particle size measurement systems, namely, inertial separation and optical or electrical mobility measurement. The majority of all particle sizing currently performed in source testing uses equipment based on inertial separation. Data in this report are primarily the result of measurements using either of two inertial instruments, the cascade impactor or the Source Assessment Sampling System (SASS) three-cyclone train.

The data were reviewed; classified according to type of fuel, combustion process, and particulate control device; analyzed; and ranked from A (high quality) to E (low quality) according to the criteria provided in the report "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections," (Ref. 4). Data expected to be more representative, as described in Section 3, are ranked higher and preferentially used in emission factor development. After ranking the data, a size distribution and size-specific emission factor were calculated for each source category, taking into consideration the data quantity and quality and the particulate emission factor obtained from AP-42 or estimated by applying a nominal particulate control device efficiency (Ref. 5) to an AP-42 particulate emission factor. The reliability of this emission factor is indicated by an emission factor rating. The ratings are subjective quality evaluations rather than statistical confidence intervals and range from A (excellent) to E (poor) as described in Section 3.

It was beyond the scope of this report to analyze process technology and particulate control device technology in detail. However, future revisions may want to subclassify emissions sources in greater detail. As an example, newer electrostatic precipitators (ESP's) would generally be larger and have a higher particulate collection efficiency than older ESP's installed on a similar source. A subclassification using ESP efficiency, age, or relative size may then yield a more useable size-specific emission factor.

A description of the external combustion sources was abstracted from AP-42 and included in Section 2. The descriptions in AP-42 were not extensively revised having recently been updated and are included in Section 2 to provide general background information. Because of the nature of AP-42, certain duplication of information occurs in Sections 1 through 3 and the proposed AP-42 sections of this report.

During a review cycle for this report, a comment was received concerning salt-laden wood waste and boiler types. In this, the final report, cumulative size-specific particle size distribution data is now shown separately by boiler types for wood waste and salt-laden wood waste. Since insufficient data was available to generate salt-laden particulate emission factors, salt-laden cumulative size-specific emission factors were not able to be calculated at this time and are therefore not presented in AP-42. Wood waste boiler types are now noted with each cumulative size-specific particle size distribution and cumulative size-specific emission factor. Since insufficient data was available to generate a particulate emission factor for a wood-waste fired fluidized bed boiler, a cumulative size-specific emission factor was not able to be calculated at this time and cannot be included in AP-42.

SECTION 2

EXTERNAL COMBUSTION SOURCES (REF. 1)

2.1 GENERAL

External combustion sources include steam/electric generating plants, industrial boilers, and commercial and domestic combustion units. Coal, fuel oil, and natural gas are the major fossil fuels used by these sources. Other fuels, used in relatively small quantities, are liquefied petroleum gas, wood, coke, refinery gas, blast furnace gas, and other waste or byproduct fuels. Coal, oil, and natural gas currently supply about 95 percent of the total thermal energy consumed in the United States. In 1980 the nation consumed over 530 million megagrams (585 million tons) of bituminous coal, nearly 3.6 million megagrams (4 million tons) of anthracite coal, 91×10^9 liters (24 billion gallons) of distillate oil, 114×10^9 liters (37 billion gallons) of residual oil, and 57×10^{12} m^3 (20 trillion ft^3) of natural gas.

Power generation, process heating, and space heating are some of the largest fuel combustion sources of sulfur oxides, nitrogen oxides, and particulate emissions. The following subsections present a brief description of the processes used to combust coal, fuel oil, natural gas, and wood waste and control particulate emissions. Other fuels are not discussed in this report.

2.2 BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

2.2.1 General

Coal is a complex combination of organic matter and inorganic ash formed over eons from successive layers of fallen vegetation. Coal types are broadly classified as anthracite, bituminous, subbituminous, or lignite, and classification is made by heating values and amounts of fixed carbon, volatile matter, ash, sulfur, and moisture. Formulas for differentiating coals based on these properties are given in Ref. 6. See Sections 2.3 and 2.7 for discussions of anthracite and lignite, respectively.

There are two major coal combustion techniques, suspension firing and grate firing. Suspension firing is the primary combustion mechanism in pulverized coal and cyclone systems. Grate firing is the primary mechanism in underfeed and overfeed stokers. Both mechanisms are employed in spreader stokers.

Pulverized-coal furnaces are used primarily in utility and large industrial boilers. In these systems, the coal is pulverized in a mill to the consistency of talcum powder (i.e., at least 70 percent of the particles will pass through a 200-mesh sieve). The pulverized coal is generally entrained in primary air before being fed through the burners to the combustion chamber, where it is fired in suspension. Pulverized-coal furnaces are classified as either dry or wet bottom, depending on the ash removal technique. Dry-bottom furnaces fire coals with high ash fusion temperatures, and dry ash removal techniques are used. In wet-bottom (slag tap) furnaces, coals with low ash fusion temperatures are used, and molten ash is drained from the bottom of the furnace. Pulverized coal furnaces are further classified by the firing position of the burners, i.e., single (front or rear) wall, horizontally opposed, vertical, tangential (corner fired), turbo or arch fired.

Cyclone furnaces burn low ash fusion temperature coal crushed to a 4-mesh size. The coal is fed tangentially, with primary air, to a horizontal cylindrical combustion chamber. In this chamber, small coal particles are burned in suspension, while the larger particles are forced against the outer wall. Because of the high temperatures developed in the relatively small furnace volume, and because of the low fusion temperature of the coal ash, much of the ash forms a liquid slag which is drained from the bottom of the furnace through a slag tap opening. Cyclone furnaces are used mostly in utility and large industrial applications.

In spreader stokers, a flipping mechanism throws the coal into the furnace and onto a moving fuel bed. Combustion occurs partly in suspension and partly on the grate. Because of significant carbon in the particulate, flyash reinjection from mechanical collectors is commonly employed to improve boiler efficiency. Ash residue in the fuel bed is deposited in a receiving pit at the end of the grate.

In overfeed stokers, coal is fed onto a traveling or vibrating grate, and it burns on the fuel bed as it progresses through the furnace. Ash particles fall into an ash pit at the rear of the stoker. The term "overfeed" applies because the coal is fed onto the moving grate under an adjustable gate. Conversely, in "underfeed" stokers, coal is fed into the firing zone from underneath by mechanical rams or screw conveyers. The coal moves in a channel, known as a retort, from which it is forced upward, spilling over the top of each side to form and to feed the fuel bed. Combustion is completed by the time the bed reaches the side dump grates from which the ash is discharged to shallow pits. Underfeed stokers include single retort units and multiple retort units, the latter having several retorts side by side.

2.2.2 Particulate Emissions and Controls

Particulate composition and emission levels are a complex function of firing configuration, boiler operation, and coal properties. In pulverized-coal systems, combustion is almost complete, and thus particulate is largely comprised of inorganic ash residue. In wet-bottom, pulverized-coal units and cyclones, the quantity of ash leaving the boiler is less than in dry-bottom units, since some of the ash liquifies, collects on the furnace walls, and drains from the furnace bottom as molten slag. In an effort to increase the fraction of ash drawn off as wet slag and thus to reduce the flyash disposal problem, flyash is sometimes reinjected from collection equipment into slag tap systems. Ash from dry-bottom units may also be reinjected into wet-bottom boilers for this same purpose.

Because a mixture of fine and coarse coal particles is fired in spreader stokers, significant unburnt carbon can be present in the particulate. To improve boiler efficiency, flyash from collection devices (typically mechanical collectors) is sometimes reinjected into spreader-stoker furnaces. This practice can dramatically increase the particulate loading at the boiler outlet and, to a lesser extent, at the mechanical collectors outlet. Flyash can also be reinjected from the boiler, air heater, and economizer dust hoppers. Flyash reinjection from these hoppers does not increase particulate loadings nearly as much as from multiple cyclones.

Particulate emissions from uncontrolled overfeed and underfeed stokers are considerably lower than from pulverized-coal units and spreader stokers, since combustion takes place in a relatively quiescent fuel bed. Flyash reinjection is not practiced in these kinds of stokers.

Variables other than firing configuration and flyash reinjection can affect emissions from stokers. Particulate loadings will often increase as load increases (especially as full load is approached) and with sudden load changes. Similarly, particulate can increase as the ash and fines contents increase. ("Fines" are defined in this context as coal particles smaller than one sixteenth inch, or about 1.6 mm, in diameter.) Conversely, particulate can be reduced significantly when overfire air pressures are increased.

The primary kinds of particulate control devices used for coal combustion include multiple cyclones, electrostatic precipitators (ESP's), fabric filters (baghouses) and scrubbers. Some measure of control will even result due to ash settling in boiler/air heater/economizer dust hoppers, large breeches, and chimney bases.

ESP's are the most common high-efficiency control device used on pulverized-coal and cyclone units, and they are being used increasingly on stokers. Generally, ESP collection efficiencies are a function of collection plate area per volumetric flowrate of flue gas through the device. Total mass particulate control efficiencies of 99.9 weight percent are obtainable with ESP's. Recently, the use of fabric filters has increased in both utility and industrial applications, generally effecting about 99.8 percent total mass efficiency. An advantage of fabric filters is that they are unaffected by high flyash resistivities associated with low-sulfur coals. ESP's located after air preheaters (i.e., cold side precipitators) may operate at significantly reduced efficiencies when low-sulfur coal is fired. Scrubbers are also used to control particulate, although their primary use is to control sulfur oxides. One drawback of scrubbers is the high energy required to achieve control efficiencies comparable to those of ESP's and baghouses.

Mechanical collectors, generally multiple cyclones, are the primary means of control on many stokers and are sometimes installed upstream of high-efficiency control devices to reduce the ash collection burden. Depending on the application and design, multiple-cyclone efficiencies can vary tremendously. Where cyclone design flowrates are not attained (which is common with underfeed and overfeed stokers), these devices may be only marginally effective and may not prove to be any better in reducing particulate than large breeching. Conversely, well-designed multiple cyclones operating at the required flowrates can achieve collection efficiencies on spreader-stokers and overfeed stokers of 90 to 95 percent. Even higher collection efficiencies are obtainable on spreader stokers with reinjected flyash because of the larger particle sizes and increased particulate loadings reaching the controls.

2.3 ANTHRACITE COAL COMBUSTION

2.3.1 General

Anthracite coal is a high-rank coal with a high fixed-carbon content and low volatile-matter content, relative to bituminous coal and lignite, and it has higher ignition and ash fusion temperatures. Because of its low volatile matter content and slight clinkering, anthracite is most commonly fired in medium-sized, traveling-grate stokers and small hand-fired units. Some anthracite (occasionally along with petroleum coke) is used in pulverized-coal-fired boilers. It is also blended with bituminous coal. None is fired in spreader stokers. Because of its low sulfur content (typically less than 0.8 weight percent) and minimal smoking tendencies, anthracite is considered a desirable fuel where readily available.

In the United States, all anthracite is mined in Northeastern Pennsylvania and is consumed primarily in Pennsylvania and several surrounding states. The largest use of anthracite is for space heating. Lesser amounts are used for steam/electric production, coke manufacturing, sintering, and pelletizing, and other industrial uses. Anthracite combustion currently is only a small fraction of the total quantity of coal combusted in the United States.

2.3.2 Particulate Emissions and Controls

Particulate emissions from anthracite combustion are a function of furnace firing configuration, firing practices (boiler load, quantity and location of underfire air, sootblowing, flyash reinjection, etc.), and the ash content of the coal. Pulverized-coal-fired boilers emit the highest quantity of particulate per unit of fuel because they fire the anthracite in suspension, which results in a high percentage of ash carryover into the exhaust gases. Pulverized-anthracite-fired boilers operate in the dry-tap or dry-bottom mode because of anthracite's characteristically high ash fusion temperature. Traveling-grate stokers and hand-fired units produce much less particulate per unit of fuel fired because combustion takes place in a quiescent fuel bed without significant ash carryover into the exhaust gases. In general, particulate emissions from traveling-grate stokers will increase during sootblowing and flyash reinjection and with higher fuel bed underfeed air from forced draft fans. Smoking is rarely a problem because of the low volatile matter content of the anthracite.

Control of emissions from anthracite combustion has mainly been limited to particulate matter. The most efficient particulate controls -- fabric filters, scrubbers, and ESP's -- have been installed on large pulverized-anthracite-fired boilers. Fabric filters and venturi scrubbers can effect total mass collection efficiencies exceeding 99 percent. ESP's, on the other hand, are typically only 90 to 97 percent total mass collection efficient, because of the characteristic high resistivity of low-sulfur anthracite flyash. It is reported that higher efficiencies can be achieved using larger precipitators and flue gas conditioning. Mechanical collector are frequently used upstream from these devices for large particle removal.

Traveling-grate stokers are often uncontrolled. Indeed, particulate control has often been considered unnecessary because of the low smoking tendencies of anthracite and because a significant fraction of large-size flyash from stokers is readily collected in flyash hoppers, as well as in the breeching and base of the stack. Cyclone collectors have been used on traveling-grate stokers and limited information suggests these devices may be up to 75 percent efficient on total mass particulate collection. Flyash reinjection, frequently used in traveling-grate stokers to enhance fuel use efficiency, tends to increase particulate emissions per unit of fuel combusted.

2.4 FUEL OIL COMBUSTION

2.4.1 General

Fuel oils are broadly classified into two major types, distillate and residual. Distillate oils (fuel oil grade nos. 1 and 2) are used mainly in domestic and small commercial applications in which easy fuel burning is required. Distillates are more volatile and less viscous than residual oils, having negligible ash and nitrogen contents and usually contain less than 0.3 weight percent sulfur. Residual oils (grade nos. 4, 5, and 6), on the other hand, are used mainly in utility, industrial, and large commercial applications with sophisticated combustion equipment. No. 4 oil is sometimes classified as a distillate, and no. 6 is sometimes referred to as Bunker C. Being more viscous and less volatile than distillate oils, the heavier residual oils (nos. 5 and 6) may need to be heated to facilitate handling and proper atomization. Because residual oils are produced from the residue left after lighter fractions (gasoline, kerosene, and distillate oils) have been removed from the crude oil, residual oils contain significant quantities of ash, nitrogen, and sulfur.

2.4.2 Particulate Emissions and Controls

Particulate emissions are most dependent on the grade of fuel fired. The lighter distillate oils result in significantly lower particulate formation than do the heavier residual oils. Among residual oils, nos. 4 and 5 usually result in less particulate than does the heavier no. 6.

In boilers firing no. 6, particulate emissions can be described, on the average, as a function of the sulfur content of the oil. Particulate emissions can be reduced considerably when low-sulfur grade no. 6 oil is fired. This is because low-sulfur no. 6, whether refined from naturally occurring low-sulfur crude oil or desulfurized by one of several current processes, exhibits substantially lower viscosity and reduced asphaltene, ash, and sulfur -- all of which results in better atomization and cleaner combustion.

Boiler load can also affect particulate emissions in units firing no. 6 oil. At low load conditions, particulate emissions may be lowered by 30 to 40 percent from utility boilers and by as much as 60 percent from small industrial and commercial units. No significant particulate reductions have been noted at low loads from boilers firing any of the lighter grades, however. At too low a load condition, proper combustion conditions cannot be maintained, and particulate emissions may increase drastically. It should be noted, in this regard, that any condition that prevents proper boiler operation can result in excessive particulate formation.

Flue gas cleaning equipment generally is used only on large oil-fired boilers. Mechanical collectors, a prevalent type of control device, are primarily useful in controlling particulates generated during soot blowing, upset conditions, or when a very dirty, heavy oil is fired. During these situations, high-efficiency cyclonic collectors can effect up to 85 percent control of particulate. Under normal firing conditions or when a clean oil is combusted, cyclonic collectors will not be nearly as effective due to a high percentage of small particles (less than 3 microns in diameter) being emitted.

ESP's are commonly used in oil-fired powerplants. Older precipitators which are also small precipitators generally remove 40 to 60 percent of the total particulate matter emissions. Due to the low ash content of the oil, greater total mass collection efficiency may not be required. Today, new or rebuilt ESP's have total mass collection efficiencies of up to 90 percent.

Scrubbing systems have been installed on oil-fired boilers, especially recently, to control both sulfur oxides and particulate. These systems can achieve SO_2 removal efficiencies of up to 90 to 95 percent and provide particulate control efficiencies of approximately 50 to 60 percent.

2.5 NATURAL GAS COMBUSTION

2.5.1 General

Natural gas is one of the major fuels used throughout the country. It is used mainly for power generation, industrial process steam and heat production, and domestic and commercial space heating. The primary component of natural gas is methane, although varying amounts of ethane and smaller amounts of nitrogen, helium, and carbon dioxide are also present. Gas processing plants are required for recovery of liquefiable constituents and removal of hydrogen sulfide (H_2S) before the gas is used. The average gross heating value of natural gas is approximately 9,350 kcal/scm (1,050 Btu/scf), usually varying from 8,900 to 9,800 kcal/scm (1,000 to 1,100 Btu/scf).

Because natural gas in its original state is a gaseous, homogenous fluid, its combustion is simple and can be precisely controlled. Common excess air rates range from 10 to 15 percent, but some large units operate at lower excess air rates to increase efficiency and reduce nitrogen oxide (NO_x) emissions.

2.5.2 Particulate Emissions and Controls

Although natural gas is considered to be a relatively clean fuel, some emissions can occur from the combustion reaction. For example, improper operating conditions, including poor mixing, insufficient air, etc., may cause large amounts of smoke, carbon monoxide, and hydrocarbons to be produced. A sulfur-containing mercaptan is added to natural gas for detection purposes, therefore, small amounts of sulfur oxides will also be produced in the combustion process. However, nitrogen oxides are the major pollutants of concern when burning natural gas. Particulate control equipment is not normally used on natural-gas-fired equipment due to extremely low particulate loading.

2.6 WOOD WASTE COMBUSTION IN BOILERS

2.6.1 General

The burning of wood waste in boilers is mostly confined to those industries where it is available as a byproduct. It is burned to obtain heat energy and alleviate possible solid waste disposal problems. Wood waste may include large pieces like slabs, logs, and bark strips as well as cuttings, shavings, pellets, and sawdust. Heating values for this waste range from about 4,400 to 5,000 kilocalories per kilogram of fuel dry weight (7,940 to 9,131 Btu/lb). However, because of typical moisture contents of 40 to 75 percent, the heating values for many wood waste materials as fired range as low as 2,200 to 3,300 kilocalories per kilogram of fuel. Generally, bark is the major type of waste burned in pulp mills, and a varying mixture of wood and bark waste, or wood waste alone, are most frequently burned in the lumber, furniture, and plywood industries.

2.6.2 Firing Practices

A variety of boiler firing configurations is used for burning wood waste. One common type in smaller operations is the dutch oven, or extension type of furnace with a flat grate. This unit is widely used because it can burn fuels with a very high moisture content. Fuel is fed into the oven through apertures at the top of a firebox and is fired in a cone-shaped pile on a flat grate. The burning is done in two stages, drying and gasification, and combustion of gaseous products. The first stage takes place in a cell separated from the boiler section by a bridge wall. The combustion stage takes place in the main boiler section. The dutch oven is not responsive to changes in steam load, and it provides poor combustion control.

In a fuel cell oven, the fuel is dropped onto suspended fixed grates and is fired in a pile. Unlike the dutch oven, the fuel cell also uses combustion air preheating and repositioning of the secondary and tertiary air injection ports to improve boiler efficiency.

In many large operations, more conventional boilers have been modified to burn wood waste. These units may include spreader stokers with traveling grates, vibrating-grate stokers, etc., as well as tangentially fired or cyclone-fired boilers. The most widely used of these configurations is the spreader stoker. Fuel is dropped in front of an air jet which casts the fuel out over a moving grate, spreading it in an even, thin blanket. The burning is done in three stages in a single chamber, (1) drying, (2) distillation and burning of volatile matter, and (3) burning of carbon. This type of operation has a fast response to load changes, has improved combustion control, and can be operated with multiple fuels. Natural gas or oil are often fired in spreader-stoker boilers as auxiliary fuel. This is done to maintain constant steam when the wood waste supply fluctuates and/or to provide more steam than is possible from the waste supply alone.

Sander dust is often burned in various boiler types, especially those in plywood, particle board, and furniture plants. Sander dust contains fine wood particles with a low moisture content (less than 20 weight percent). It is fired in a flaming horizontal torch, usually with natural gas as an ignition aid or supplementary fuel.

2.6.3 Particulate Emissions and Controls

The major pollutant of concern from wood boilers is particulate matter, although other pollutants, particularly carbon monoxide, may be emitted in significant amounts under poor operating conditions. These emissions depend on a number of variables, including (1) the composition of the waste fuel burned, (2) the degree of flyash reinjection employed, and (3) furnace design and operating conditions.

The composition of wood waste depends largely on the industry from which it originates. Pulping operations, for example, produce great quantities of bark that may contain more than 70 weight percent moisture and sand and other noncombustibles. Because of this, bark boilers in pulp mills may emit considerable amounts of particulate matter to the atmosphere unless they are well controlled. On the other hand, some operations such as furniture manufacture produce a clean, dry (5 to 50 weight percent moisture) wood waste that results in relatively few particulate emissions when properly burned. Other operations, such as sawmills, burn a variable mixture of bark and wood waste that results in particulate emissions somewhere between these two extremes.

Furnace design and operating conditions are particularly important when firing wood waste. For example, because of the high moisture content that can be present in this waste, a larger than usual area of refractory surface is often necessary to dry the fuel before combustion. In addition, sufficient secondary air must be supplied over the fuel bed to burn the volatiles that account for most of the combustible material in the waste. When proper drying conditions do not exist, or when secondary combustion is incomplete, the combustion temperature is lowered, and increased particulate, carbon monoxide, and hydrocarbon emissions may result. Lowering of combustion temperature generally results in decreased nitrogen oxide emissions. Also, emissions can fluctuate in the short term due to significant variations in fuel moisture content over short periods of time.

Flyash reinjection, which is common in many larger boilers to improve fuel efficiency, has a considerable effect on particulate emissions. Because a fraction of the collected flyash is reinjected into the boiler, the dust loading from the furnace, and consequently from the collection device, increases significantly per unit of wood waste burned. It is reported that full reinjection can cause a tenfold increase in the total dust loadings of some systems, although increases of 1.2 to 2 times are more typical for boilers using 50 to 100 percent reinjection. A major factor affecting this dust loading increase is the extent to which the sand and other noncombustibles can successfully be separated from the flyash before reinjection to the furnace.

Although reinjection increases boiler efficiency from 1 to 4 percent and minimizes the emissions of uncombusted carbon, it also increases boiler maintenance requirements, decreases average flyash particle size and makes collection more difficult. Properly designed reinjection systems should separate sand and char from the exhaust gases to reinject the larger carbon particles to the furnace and to divert the fine sand particles to the ash disposal system.

Several factors can influence emissions, such as boiler size and type, design features, age, load factors, wood species, and operating procedures. In addition, wood is often cofired with other fuels. The effect of these factors on emissions is difficult to quantify. It is best to refer to the references for further information.

The use of multitube cyclone multiple cyclones provides the particulate control for many hogged boilers. Usually, two sets of multiple cyclones used in series, allowing the first collector to remove the bulk of the dust and the second collector to remove smaller particles. The total mass collection efficiency for this arrangement is from 65 to 95 percent. Low-pressure drop scrubbers and fabric filters have been used extensively for many years. On the West Coast, pulse jets have been used.

2.7 LIGNITE COMBUSTION

2.7.1 General

Lignite is a relatively young coal with properties intermediate to those of bituminous coal and peat. It has a high moisture content (35 to 40 weight percent) and a low, wet basis heating value (1,500 to 1,900 kilocalories per kilogram) and generally is burned only close to where it is mined, in some midwestern states and in Texas. Although a small amount is used in industrial and domestic situations, lignite is mainly used for steam/electric production in powerplants. In the past, lignite was burned mainly in small stokers, but today the trend is toward use in much larger pulverized-coal-fired or cyclone-fired boilers.

The major advantages of firing lignite are that, in certain geographical areas, it is plentiful, relatively low in cost, and low in sulfur content (0.4 to 1 wet basis weight percent). The major disadvantages are that more fuel and larger facilities are required to generate a unit of power than is necessary with bituminous coal. There are several reasons for this. First, the higher moisture content means that more energy is lost in the gaseous combustion, which reduces boiler efficiency; second, more energy is required to grind lignite to the combustor-specified size, especially in pulverized-coal-fired units; third, greater tube spacing and additional sootblowing are required because of the higher ash fouling tendencies and, fourth, because of its lower heating value, more fuel must be handled to produce a given amount of power, since lignite usually is not cleaned or dried before combustion (except for some drying that may occur in the crusher or pulverizer and during transfer to the burner). Generally, no major problems exist with the handling or combustion of lignite when its unique characteristics are taken into account.

2.7.2 Particulate Emissions and Controls

The major pollutants of concern when firing lignite, as with any coal, are particulates, sulfur oxides, and nitrogen oxides. Volatile organic compound (VOC) and carbon monoxide emissions are quite low under normal operating conditions.

Particulate emission levels appear most dependent on the firing configuration in the boiler. Pulverized-coal-fired units and spreader stokers, which fire all or much of the lignite in suspension, emit the greatest quantity of flyash per unit of fuel burned. Cyclones, which collect much of the ash as molten slag in the furnace itself, and stokers (other than spreader), which retain a large fraction of the ash in the fuel bed, both emit less particulate matter. In general, the relatively high sodium content of lignite lowers particulate emissions by causing more of the resulting flyash to deposit on the boiler tubes. This is especially so in pulverized-coal-fired units wherein a high fraction of the ash is suspended in the combustion gases and can readily come into contact with the boiler surfaces.

Newer lignite-fired utility boilers are equipped with large ESP's that may achieve as high as 99.5 percent total mass particulate control. Older and smaller ESP's operate at about 95 percent total mass collection efficiency. Older industrial and commercial units use cyclone collectors that normally achieve 60 to 80 percent total mass collection efficiency on lignite flyash. Flue gas desulfurization systems currently are in operation on several lignite-fired utility boilers. These systems are identical to those used on bituminous-coal-fired boilers.

SECTION 3

PARTICLE SIZE DISTRIBUTION FOR EXTERNAL COMBUSTION SOURCES

Cumulative size-specific emission factors for the external combustion source categories listed in Section 1 are presented in this section. The subsections identify the data obtained and reviewed for inclusion into the size-specific emission factors, the data categorization by emission source and control device, size-specific emissions on a weight percent with a data quality ranking, particulate emission factor estimates, and, finally, recommended cumulative size-specific emission factors. Particle sizes used in the emission factors are usually expressed in terms of the aerodynamic equivalent diameter. This method of size expression is useful because it is readily determined through straightforward measurement; a particle's inertial characteristics can be used to best predict where deposition will occur in the respiratory system; and actual particle size and density may not be obtainable. Small particles are not likely to be round and may be hollow or deeply cratered spheres.

There are two general classifications of particle size measurement systems, namely, inertial separation and optical or electrical mobility measurement. The majority of all particle sizing currently performed in source testing uses equipment based on inertial separation. Data in this report are primarily the result of measurements using either of two inertial instruments, the cascade impactor or the Source Assessment Sampling System (SASS) three-cyclone train.

The cascade impactor is a low-speed impaction device in which jet stages and impaction plates are paired. The second jet stage has less open area than the first, so the air moves through it faster and undergoes more acceleration in turning to flow around the impaction plate. Thus the second stage impaction plate is able to collect smaller particles. The cascade impactor is designed so that each plate collects particles of one size range expressed as d_{50}, the particle size in microns for which 50 percent of the particles are theoretically collected on a particular sampling plate or stage. The cross section of an Andersen Mark III cascade impactor is shown in Figure 1. Cascade impactors of similar design and significantly different designs are offered by several companies.

The SASS train is a system consisting of three cyclones and a filter in series. It is primarily used to obtain sufficient particulate for trace element and organics analyses. The SASS may be used to determine the total particulate concentration plus particulate concentrations in the greater than 10 µm, less than 10 µm but greater than 3 µm, less than 3 µm but greater than

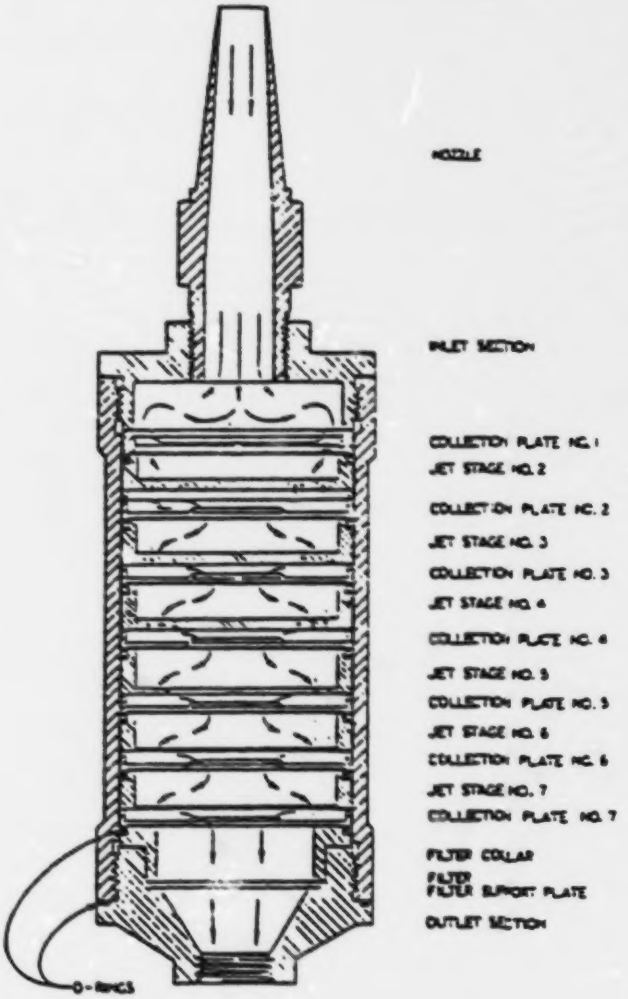

NOZZLE
INLET SECTION
COLLECTION PLATE NO. 1
JET STAGE NO. 2
COLLECTION PLATE NO. 2
JET STAGE NO. 3
COLLECTION PLATE NO. 3
JET STAGE NO. 4
COLLECTION PLATE NO. 4
JET STAGE NO. 5
COLLECTION PLATE NO. 5
JET STAGE NO. 6
COLLECTION PLATE NO. 6
JET STAGE NO. 7
COLLECTION PLATE NO. 7
FILTER COLLAR
FILTER
FILTER SUPPORT PLATE
OUTLET SECTION
O-RINGS

Figure 1. Cross section of Andersen Mark III cascade impactor.

1 µm, and less than 1 µm particulate size ranges. The SASS train does not provide a sufficient number of particulate size cutpoints to be a preferred sampling system for determining size distribution but is based on generally sound methodology.

The particle size distribution of emissions from different points within a particular source category is expected to vary just as total mass emissions from similar processes vary. It is possible that emissions from a specific point may vary significantly from others in the same category. The data presented herein are considered typical for that category. Quality ratings of emission factors indicate relative levels of confidence in the data's representativeness for similar processes operated in an average manner. Differences may result from subtle or gross differences in design, operating conditions, feedstocks, control device performance, and maintenance programs. Care should be taken to remember these limitations when using the particle size distributions presented herein, and emission factors in general.

A literature review was also conducted to locate inhalable particulate data. Reports that included the results of measurements and observations of the author were considered as primary sources and were considered the most highly desirable for use in calculating inhalable particulate emission factors. (Individual FPEIS test series were considered primary sources.) Secondary sources were those in which the author reported emission data performed by a different organization. When attempts failed to obtain the primary sources on which key secondary sources were based, it became necessary to utilize those secondary sources in the development of inhalable particulate emission factors. Many individual FPEIS test series were researched to ensure proper classification of the data.

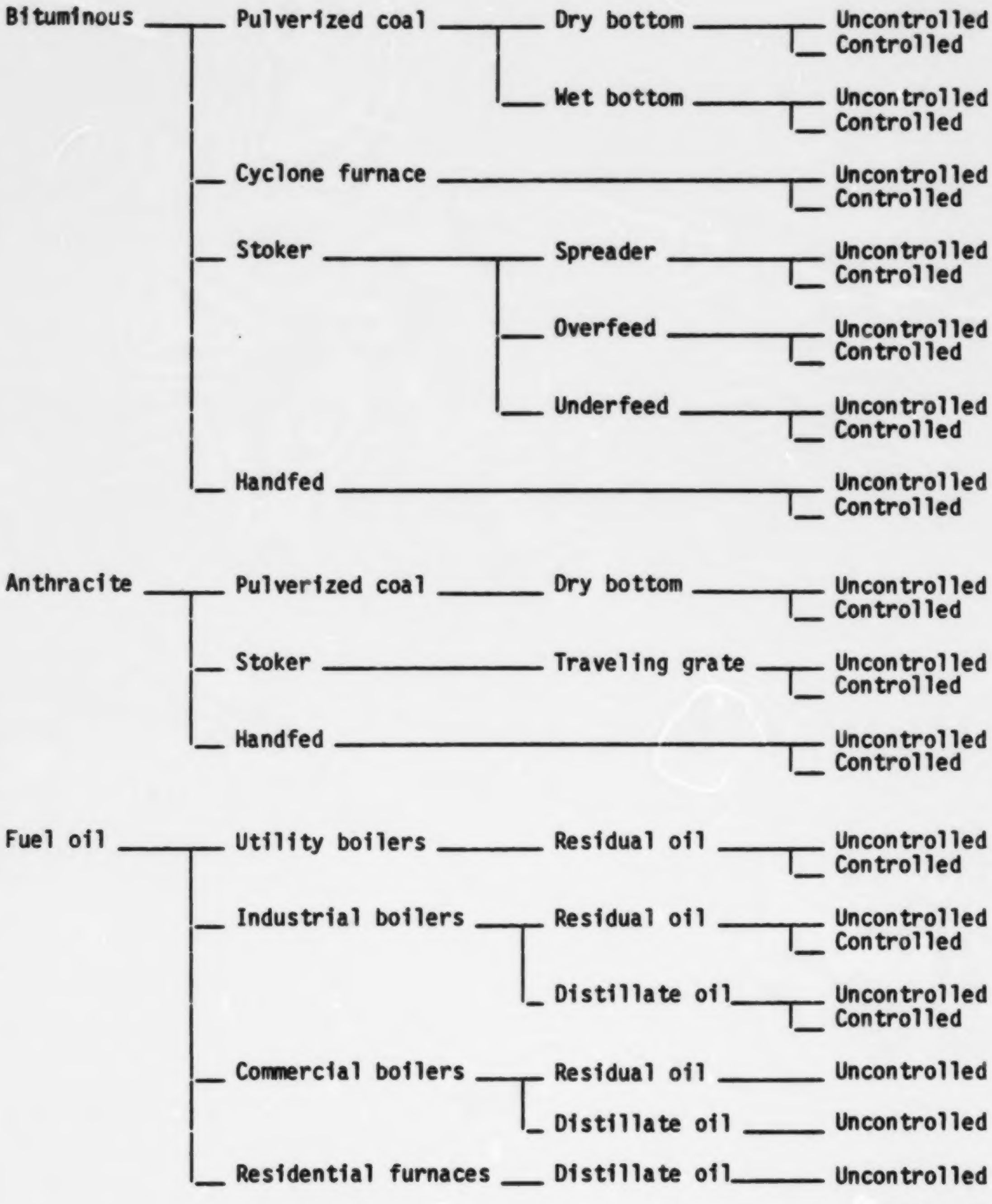
3.1 DATA COLLECTION

Information was sought for categories shown in Figure 2. Data sources used for the development of size-specific emission factors are listed in Table 1. FPEIS was used as a primary data source.

Several FPEIS test series and reports provided by others were reviewed and found to be not useable for emission factor development. Those FPEIS test series numbers plus other reports and data sources are listed in Table 2 along with an explanation.

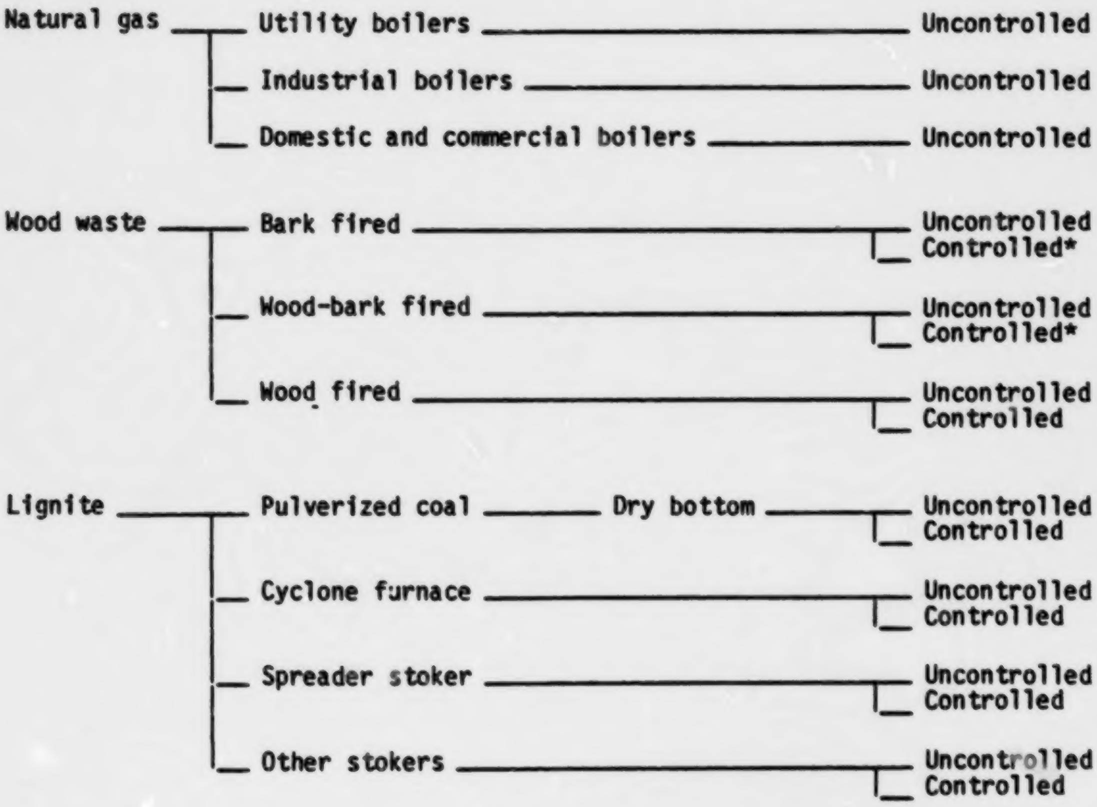
3.2 DATA CATEGORIZATION

The FPEIS printouts and other sources of data were reviewed to determine the appropriate data categorization by emission source and control device. In evaluating the data for its usefulness, sufficient information was required to assign the data to a specific source category, to establish the representativeness of the emission source, control device, and operating conditions, and to identify the particle sampling method, conditions, and results. To assign data to a specific source category required identification of the fuel, emission source, and control device. It was necessary in cases with some solid fuels to establish whether or not flyash


Bituminous
Pulverized coal
Dry bottom
Uncontrolled
Controlled
Wet bottom
Uncontrolled
Controlled
Cyclone furnace
Uncontrolled
Controlled
Stoker
Spreader
Uncontrolled
Controlled
Overfeed
Uncontrolled
Controlled
Underfeed
Uncontrolled
Controlled
Handfed
Uncontrolled
Controlled
Anthracite
Pulverized coal
Dry bottom
Uncontrolled
Controlled
Stoker
Traveling grate
Uncontrolled
Controlled
Handfed
Uncontrolled
Controlled
Fuel oil
Utility boilers
Residual oil
Uncontrolled
Controlled
Industrial boilers
Residual oil
Uncontrolled
Controlled
Distillate oil
Uncontrolled
Controlled
Commercial boilers
Residual oil
Uncontrolled
Distillate oil
Uncontrolled
Residential furnaces
Distillate oil
Uncontrolled

(continued)

Figure 2. Categories for which data was sought for the development of size-specific emission factors.


Natural gas
Utility boilers
Uncontrolled
Industrial boilers
Uncontrolled
Domestic and commercial boilers
Uncontrolled
Wood waste
Bark fired
Uncontrolled
Controlled*
Wood-bark fired
Uncontrolled
Controlled*
Wood fired
Uncontrolled
Controlled
Lignite
Pulverized coal
Dry bottom
Uncontrolled
Controlled
Cyclone furnace
Uncontrolled
Controlled
Spreader stoker
Uncontrolled
Controlled
Other stokers
Uncontrolled
Controlled

*With and without flyash reinjection to boiler for additional carbon burnup.

Figure 2. (continued)

TABLE 1. DATA SOURCES USED FOR THE DEVELOPMENT OF SIZE-SPECIFIC EMISSION FACTORS

Source category	FPEIS test series numbers[a] (Ref. 2, 3)			Other data sources
Bituminous and subbituminous coal combustion	13		181	EMB Report 80-1BR-12 (Ref. 7)
	15	128	182	EMB Report 82-1BR-17 (Ref. 8)
	16	129	183	EMB Report 82-1BR-18 (Ref. 9)
	29	130	242	EPA 68-02-3271 (Ref. 10)
	35	169	248	EPA 600/7-81-020A (Ref. 11)
	36	171	250	Ohio Edison Co. (Ref. 12)
	37	172	251	
	38	173	252	
	39	174	262	
	40	175	264	
	57	176	267	
	63	177	274	
	64	178	281	
	81	179	307	
	115	180		
Anthracite coal combustion	11	99	247	
	73	100	253	
	74	101	254	
	75	102		
	98	103		
Fuel oil combustion	14	62	198	TR-83-110/EE (Ref. 13)
	17	66	205	
	22	67	206	
	23	72	207	
	24	170	212	
	59	186	213	
	60	188	214	
	61	192		
Natural gas combustion				EPA 68-02-3512 (Ref. 5)

(continued)

TABLE 1. (continued)

Source category	FPEIS test series numbers (Ref. 2,3)			Other data sources
Wood waste combustion in boilers	109 138	141[b] 256 257	258 259 260[c]	EMB Report 80-WFB-2 (Ref. 14) EMB Report 80-WFB-4 (Ref. 15) EMB Report 80-WFB-5 (Ref. 16) EMB Report 80-WFB-8 (Ref. 17) EMB Report 80-WFB-9 (Ref. 18)[b] EMB Report 80-WFB-10 (Ref. 19) NCASI (Ref. 20)
Lignite combustion	166	167	168	ERC #7246 (Ref. 21)

[a] The total mass and particle size data for each FPEIS test series listed in Tables 1 and 2 are given in FPEIS Computer Printout A4F361(Ref. 2) or 43CETA (Ref. 3). Reference 22 lists the original reference document for each FPEIS test series as of August, 1986.

[b] Although originally intended to be used in the development of size-specific emission factors, these tests used salt-laden wood wastes with insufficient data to generate a reliable particulate emission factor. Size distributions are presented in this report (but not in the AP-42 section) for informational purposes and may be of value for future revisions to AP-42.

[c] Although originally intended to be used in the development of size-specific emission factors, this test reported on emissions from a fluidized bed boiler. Insufficient data exists to generate a reliable particulate emission factor. Size distributions are presented in this report (but not in the AP-42 section) for informational purposes and may be of value for future revisions to AP-42.

TABLE 2. FPEIS TEST AND OTHER REPORTS REVIEWED BUT NOT USED FOR EMISSION FACTOR DEVELOPMENT

FPEIS test series numbers						Comments
184	194	197	245	268		Insufficient number of SASS train component catches reported either due to one or two cyclones not used or data not reported
191	195	200	246	269		
193	196	201	261	270		
272	273	277				Inadequate sizing device
283						Data from original report used
12	264					Data not supported by PADRE (see Glossary of Terms)
187	276					
244	287					
292						Particulate size distribution data noted to be inconsistent and not representative
127						Operating conditions not representative due to ammonia injection and varied ESP rapping to study effect on emissions
140						Test agencies could not confirm this data but did support FPEIS test series no. 141 for same boiler
243	278	280	312*	314*	316*	Test series presented total mass emission rate data only (no particle size distribution data)
275	279	311*	313*	315*		
(*Used SASS train without cyclones)						

(continued)

TABLE 2. (continued)

FPEIS test series numbers						Comments
18	51	89**	119	125**	133**	Insufficient data for source category classification and test location listed as "confidential"
25	58	111	120	126**	163	
32	65*	116**	121**	131**	185*	
50	85	118	122**	132**	190	
					249	

(*More detailed information requested from site but not received)
(**Report requested but not received)

Other reports/data sources	Comments
General	
"Emission test report, WESTVAVCO Bleached Board Division, Covington, VA," EMB Report 80-WFB-3, February 1980.	Bark plus coal cofired boiler, therefore, not applicable to source categories under review
"Compilation of a Preliminary Particle-Sized Emission Factor Data Base," EPA-450/4-82-016, November 1982.	No primary data presented, primarily FPEIS test series data
"Fine Particulate Emission Inventory and Control Survey," by Midwest Research Institute January 1974, EPA Report No. EPA-450/3-74-040.	Limited information presented in old report. Unable to determine identity of sites used as emission sources, sampling conditions and equipment and operating conditions. Since sources are not identified, they may also be contained in FPEIS.
Bituminous Coal	
"Evaluation of the George Neal No. 3 Electro-static Precipitator," EPRI FP-1145 Project 780-1, August 1979.	Particulate size data not reported in a useable format
Anthracite Coal	
"Source Sampling of Anthracite Coal-Fired Boilers," by Scott Environmental Technology, Inc., May 1975.	Report used Coulter Counter for particle count in a liquid

(continued)

TABLE 2. (continued)

Other reports/data sources	Comments
Oil	
"Environmental Assessment of an Oil-Fired Controlled Utility Boiler," EPA-600/7-80-087, April 1980.	Due to the extremely light particulate loading, particulate size distribution data were not presented
"Emissions Assessment of Conventional Stationary Combustion Systems; Vol. 1. Gas- and Oil-Fired Residential Heating Sources," EPA-600/7-79-0296, May 1979.	SASS train used without cyclones thus no particle size distribution data were presented
"Particulate Emission Characteristics of Oil-Fired Utility Boilers," EPRI CS-1995, Research Project 1131-1, August 1981.	Reduced data not presented in a directly useable form
"Kramer Station Fabric Filter Evaluation," EPRI CS-1669, Research Project 1130-1, January 1981.	Reduced data not presented in a directly useable format
Wood	
"An Investigation of Source Particulate Measurement Procedures, Particle Sizes, and Practiced Control Technology for Wood Fuel-Fired Boilers," Atmospheric Quality Improvement Technical Bulletin No. 72, National Council of the Paper Industry for Air and Stream Improvement, Inc., June 1974.	Report does not present particulate size distributions for uncontrolled or controlled flue gas streams
"Emission Test Report, WI Forest Products Inc., Long Lake Lumber Division," EMB Report 80-WFB-11, March 1981.	Size distribution data validity extremely questionable since one to seven stages of each sample using an Andersen cascade impactor with seven stages (and a backup filter plus either a preimpactor cyclone or an eighth stage) were reported as collecting no particulate

(continued)

TABLE 2. (continued)

Other reports/data sources	Comments
Lignite	
Portions of data provided with letter from Mr. Dana Mount, North Dakota State Department of Health to Mr. A. Walter Wyss, Acurex Corporation.	
Specific Portions:	
December 17, 1980 sampling at boiler no. 6 at North Dakota State University in Fargo, North Dakota.	Sizing procedures used X-ray sedimentation
March 12, 1980 sampling at Boiler No. 7 at North Dakota State University in Fargo, North Dakota.	Sizing procedure used X-ray sedimentation
October 30, 1979 sampling at American Crystal Sugar Plant at Drayton, North Dakota.	Sizing procedure used MSA-Whitby sedimentation centrifugation
May 10, 1979 sampling on no. 91 auxiliary boiler Baghouse at the Oak Creek Station near Underwood, North Dakota.	Sizing procedure used MSA sedimentation centrifugation
October 17, 1978 sampling on boiler no. 1 at the San Haven State Hospital in Dunseith, North Dakota.	Sizing procedure used MSA sedimentation centrifugation
November 18, 1976 sampling at boiler no. 4 at North Dakota State University in Fargo, North Dakota.	Sizing procedure apparently used MSA sedimentation centrifugation
Standards Support and Environmental Impact Statement Volume 1: Proposed Standards of Performance for Lignite-Fired Steam Generators, December 1975, EPA	No particle sizing information presented

captured by a control device was reinjected into the combustor. Emission sources and control devices representative of actual units in operation were preferred over small-scale demonstration and development sources and control devices. Normal operating conditions were preferred as opposed to low-load conditions and conditions with severe operating malfunctions. Particle samples using inertial separation were preferred over other methods, but enough information was required to establish if the sampling was performed in an acceptable manner and to show completeness of sampling data. Table 3 shows the number of data sets obtained for each emission source and control device.

3.3 DATA EVALUATION

The data obtained were reviewed, analyzed, and ranked according to the criteria provided in the report "Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections," If there was no reason to exclude particular data from consideration (see Section 3.2), each data set was assigned a ranking. The data were ranked as follows:

A -- Tests performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference method tests, although such reference methods will certainly be used as a guide.

B -- Tests performed by a generally sound methodology but lacking enough detail for adequate validation

C -- Tests based on an untested or new methodology or lacking a significant amount of background data

D -- Tests based on a generally unacceptable method but which may provide an order-of-magnitude value for the source

In general, FPEIS and other data were ranked as A-quality if a standard cascade impactor was used, sampling flowrate isokinetic value was reported and fell with an acceptable range of 90 to 110 percent and sufficient operating data were listed to firmly classify the system tested into one of the categories for which a particulate emission factor has been developed. Data were typically downgraded to B-quality if the isokinetic values were not reported or were not within the 90 to 110 percent range. Reports and points of contact listed in the FPEIS data base were frequently sought to further clarify test data and operating conditions.

SASS data were generally ranked as B-quality if the sampling flowrate isokinetic value was reported and sufficient operating data was listed to firmly classify the system into one of the external combustion sources. Data were typically ranked as C-quality if the sampling isokinetic values were not reported or were reported as not within the 90 to 110 percent isokinetic flow range.

TABLE 3. EXTERNAL COMBUSTION SOURCE CATEGORIES AND IDENTIFIED DATA SETS USED FOR EMISSION FACTOR DEVELOPMENT

External combustion emission source category	Emission control device	Number of data sets
Bituminous and subbituminous coal combustion		
• Dry bottom, pulverized coal fired	None	126
	Multiple cyclones	4
	Scrubber	62
	ESP	127
	Baghouse	2
• Wet bottom, pulverized coal fired	None	3
	Multiple cyclones	1
	ESP	5
• Cyclone furnace	None	1
	Scrubber	1
	ESP	5
• Spreader stoker	None	43
	Multiple cyclone with flyash injection	1
	Multiple cyclone without flyash reinjection	11
	ESP	1
	Baghouse	59
• Overfeed stoker	None	3
	Multiple cyclones	3
• Underfeed stoker	None	6
	Multiple cyclones	--[a]
• Hand-fired units	None	--
Anthracite Coal Combustion		
• Pulverized coal fired	None	--
	Multiple cyclones	101
	Baghouse	66
• Stoker	None	3
• Hand-fed units	None	--

(continued)

TABLE 3. (continued)

External combustion emission source category	Emission control device	Number of data sets
Fuel oil combustion		
• Utility boilers, residual oil	None	28
	ESP	2
	Scrubber	4
• Industrial boilers	None	17
-- Residual oil	Multiple cyclones	1
-- Distillate oil	None	2
• Commercial boilers		
-- Residual oil	None	19
-- Distillate oil	None	3
• Residential furnaces		
-- Distillate oil	None	--
Natural gas combustion		
• Utility boilers		--
• Industrial boilers		--
• Domestic and commercial boilers		--
Wood combustion		
• Bark fired	None	11
	Multiple cyclones with flyash reinjection	9
	Multiple cyclones without flyash reinjection	--
	Scrubber	8
• Wood bark fired	None	2[b]
	Multiple cyclones with flyash reinjection	3[c]
	Multiple cyclones without flyash reinjection	4[d]
	Scrubber	2
	Baghouse	--[d]
	Dry electrostatic granular filter	9
• Wood fired	None	--

(continued)

TABLE 3. (continued)

External combustion emission source category	Emission control device	Number of data sets
Lignite coal combustion		
• Dry bottom, pulverized coal fired	None	2
	Multiple cyclone	4
• Cyclone furnace	None	--
• Spreader stoker	None	--
	Multiple cyclone	1
• Other stokers	None	--

[a] Two data sets presented but not used for emission factor development for underfeed stokers with multiple cyclone controls burning bituminous coal. Uncontrolled emissions (i.e., emissions into the control device) appeared to be approximately double average uncontrolled emissions.

[b] Three data sets also presented for salt-laden wood bark and fluidized bed boilers but not used for emission factor development at this time.

[c] Fifteen data sets also presented for salt-laden wood bark but not used for emission factor development at this time.

[d] Same as c except 3 data sets.

The rated data were grouped according to process type. In cases where a single test report presented data on two processes or both controlled and uncontrolled emission data on the same process, each was considered separately. Size-specific emission data are presented in this report in the uniform format of size ranges 0.625, 1.0, 1.25, 2.5, 6, 10, and 15 microns aerodynamic equivalent diameter. The FPEIS data base used the Particulate Data Reduction (PADRE) program for size reporting. The PADRE program is an interactive computer program that facilitates entry of validated cascade impactor data for particle size distributions from representative in-stack runs into FPEIS. PADRE was developed to ensure the quality of data included in FPEIS, which is a component of the Environmental Assessment Data Systems (EADS). Impactor stage cut points are calculated and cumulative and differential mass concentrations are determined and interpolated to standard diameters. In several cases the FPEIS data base did not report emission data for the entire size range and those data are reported without extrapolation (Ref. 2 and 3). Essentially all of the non-FPEIS test reports did not report particle size distributions in terms of the specific cut points of interest (i.e., 0.625, 1.00, 1.25, and 2.5 µm, etc.). In these cases, a computer was used to plot the reported data. A curve or line was then fit to the plotted points and the values of interest were selected. In cases where the individual runs were graphically presented in the test report, the values for the specific size ranges were read from the individual graphs and averaged arithmetically. In cases where only stage cut point and mass data were presented, the desired particle size information was acquired by arithmetically calculating percent mass less than the cutpoint and plotting the data on a log-probability graph to visually interpolate the specific size ranges.

3.3.1 Bituminous and Subbituminous Coal

Cumulative size-specific particle size distribution data for each emission source and control device for bituminous and subbituminous coal combustion are listed in Tables 4 through 23. The tables include an assigned rating for each data set.

The FPEIS data base managed by the Environmental Protection Agency was extensively used to provide data sets for this study. A discussion of these data sets and those obtained from other reports follows. The FPEIS data sets are listed numerically by their test series number (TSN) and are followed by a discussion of other relevant tests.

TSN 13

The data in this series came from emissions sampling of a 450-GJ/hr (125-MW), dry-bottom utility boiler firing pulverized bituminous coal. This unit (Widows Creek unit no. 5 near Bridgeport, Alabama operated by the Tennessee Valley Authority (TVA)) used multiple cyclones to reduce particulate emissions.

Emissions testing lasted 3 days in August of 1974. Operating loads were in the range of 96 percent to 99 percent of design capacity. Samples were

TABLE 4. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED DRY BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE#	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
13	1	2	1	1	2	4	18	32	56	B
	2	2	1	1	1	3	15	31	55	B
	3	2	1	1	2	4	18	34	57	B
15	1	1	20	38	48	75	94	98	100	D
	1	2	17	34	40	59	78	87	93	D
	2	1	45	71	82	100	100	100	100	D
	2	2	16	28	36	58	80	89	94	D
	3	1	9	18	25	47	71	83	90	D
	3	2	13	26	33	55	77	87	92	D
	3	3	13	21	33	67	91	97	99	D
16	1	1	3	19	26	48	72	84	91	D
	1	2	4	17	26	50	74	85	91	D
29	1	2	4	6	8	21	60	81	92	A
	1	3	0	1	1	8	27	44	65	A
	2	2	2	3	4	10	24	40	62	A
	3	2	0	0	1	3	7	22	49	A
	3	3		2	3	20	46	63	78	A
57	1	1		54	54	55	61	63	66	D
	1	2		4	5	10	23	31	42	B
	1	3		2	3	9	30	42	53	B
	1	4		2	3	6	20	26	34	B
	1	5			1	7	22	28	35	B
	2	1		0	0	1	7	12	19	B
	2	2		0	0	1	8	12	19	B
	2	3		1	1	3	11	16	24	B
	2	4		0	0	2	7	12	19	B
	2	5		2	2	3	10	14	21	B
	2	6		1	1	2	9	14	22	B
	2	7		1	1	2	8	13	21	B
	3	1		4	4	6	13	18	26	B
	3	2		1	1	3	12	19	27	B
	3	3		1	1	3	11	19	31	B
	3	4		1	1	2	8	13	20	B
	3	5		1	1	2	9	13	20	B
	4	1		0	1	2	10	15	22	B
	4	2		1	1	2	8	13	20	B
	4	3		1	2	3	11	16	23	B
	4	4		1	1	3	14	20	31	B
	4	5		0	1	2	9	14	21	B
	4	6		1	1	2	12	17	24	B
	5	1		1	1	2	10	15	22	B
	5	3			0	2	9	13	21	B
	5	4		1	1	3	12	17	25	B
	5	5		1	1	2	13	20	28	B
	6	1		1	1	2	10	16	24	B
	6	2		0	0	1	8	12	20	B
	6	3		1	1	2	11	16	24	B
	6	4		0	0	2	10	16	24	B
	6	5		0	0	2	9	14	22	B
	7	1		1	1	2	10	15	23	B
	7	2		0	1	2	10	15	23	B
	7	3		0	1	2	10	15	23	B
	7	4		1	1	2	9	14	21	B
	7	5		1	1	2	11	17	25	B
81	1	1	0	1	1	3	9	12	23	B
	1	2	1	1	1	4	10	12	16	B
	1	3	1	2	3	6	17	20	29	B
	1	4	0	1	1	4	12	17	23	B
	2	1	1	1	1	2	11	15	23	B
	2	2	1	1	1	4	9	13	19	B
	2	3	1	2	2	5	14	20	29	B
	2	4	0	0	1	2	7	10	18	A
	2	5	1	2	2	6	15	21	31	B
	2	6	1	1	1	3	12	15	23	B
	3	1	1	1	1	6	19	26	40	B
	3	2	1	1	1	3	16	22	33	B
	3	3	0	0	1	4	13	17	24	B

(continued)

TABLE 4. (continued)

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
115	1	1	1	2	4	9	26	35	43	B
	1	2	0	1	1	2	7	11	15	B
	1	3	2	4	5	10	22	29	40	B
	1	4	1	2	3	10	18	25	36	B
	3	1	1	1	1	3	16	25	37	B
	3	2	1	2	3	13	29	39	49	B
	3	3	0	1	1	5	12	17	25	B
	3	4	0	2	2	7	19	26	35	B
	3	5	1	2	3	13	27	40	52	B
	4	1	3	4	4	7	23	27	43	B
	4	2	0	0	1	2	7	10	16	B
	4	3	0	1	2	9	23	30	46	B
	4	4	0	1	1	6	11	31	43	B
	4	5	0	0	1	3	8	12	13	B
	5	1	3	5	6	13	30	37	51	B
	5	2	1	1	1	4	17	21	29	B
	5	3	3	4	6	16	34	43	62	B
	5	4	1	2	5	14	31	40	53	B
	6	1	2	6	6	10	20	25	36	B
	6	2	2	4	5	10	25	31	45	B
	6	3	3	4	5	10	27	32	42	B
	6	4	2	3	4	9	18	24	32	B
	8	1	2	2	3	6	13	20	29	B
	8	2	1	2	3	5	13	16	28	B
	8	3	2	3	5	12	24	28	42	B
	8	4	2	4	5	11	21	26	39	B
	9	2	2	2	4	10	18	24	38	B
128	1	1	2	2	2	6	18	23	26	B
	1	2	0	0	1	1	11	19	22	B
	2	1	0	0	1	2	15	19	21	B
	2	2	1	1	1	4	11	17	27	B
	3	1	0	1	1	3	11	18	29	B
	3	2	0	0	1	2	11	15	25	B
	4	1	0	0	0	1	6	11	23	B
	4	2	0	1	1	3	9	18	32	B
	5	1	1	1	1	3	8	12	18	B
	5	2	1	1	1	3	9	12	16	B
	6	1	2	3	3	7	14	18	27	B
	6	2	1	1	2	3	10	16	23	B
	7	1	1	1	1	3	12	15	20	B
	7	2	1	1	1	3	8	12	16	B
	8	1	0	1	1	3	13	18	23	B
130	1	1	1	5	8	20	39	42	44	B
	1	2	2	4	5	13	32	35	40	B
	2	1	0	2	3	7	34	37	42	B
	2	2	3	8	11	22	45	49	52	B
	2	3	3	2	3	14	34	38	44	B
	2	4	0	1	2	6	13	17	23	B
	2	5	2	3	3	11	24	28	31	B
	3	1	1	2	3	12	26	33	42	B
	3	2	0	1	1	4	11	14	16	B
	3	3	1	1	2	6	13	16	18	B
	4	1	1	3	4	11	25	29	36	B
	4	2	1	2	4	12	26	30	35	B
248	1	1		4	6	15	40	55	71	B
307	1	2	2	3	4	5	10	16	26	A
	1	5	4	6	7	12	21	28	38	A
	1	8	4	6	7	10	17	23	30	A
	2	2	3	3	4	6	13	16	31	A
A RANK DATA AVERAGE			2	3	4	10	23	34	49	
B RANK DATA AVERAGE			1	2	2	6	16	22	31	
A+B RANK DATA AVERAGE			1	2	2	6	17	23	32	

* SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 5. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE CYCLONE CONTROLLED DRY BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
13	1	4	0	0	0	1	13	29	54	B
	2	4	3	3	3	4	13	28	53	B
	3	4	0	0	1	3	17	31	55	B
169**	1	2		0	0	0	1	2	23	D
B RANK DATA AVERAGE			1	1	1	3	14	29	54	

*SEE TEXT FOR TEST SITE IDENTIFICATION.
**MECHANICAL COLLECTOR MALFUNCTION DURING TEST PERIOD.

TABLE 6. PARTICLE SIZE DISTRIBUTION DATA FOR SCRUBBER CONTROLLED BOILERS BURNING PULVERIZED BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
15	1	3	63	85	88	97	100	100	100	A
	1	4	24	84	89	99	100	100	100	A
	2	3	39	64	80	100	100	100	100	A
	2	4	42	73	83	100	100	100	100	A
	3	4	32	51	64	95	100	100	100	A
	3	5	48	75	79	91	98	100	100	A
	3	6	37	81	95	100	100	100	100	A
16	2	1	36	73	83	100	100	100	100	A
	2	2	29	41	42	49	65	77	86	A
57	1	6	10	12	13	25	29	44	61	B
	1	7	9	12	13	28	35	48	64	B
	1	8	5	6	7	11	15	32	53	B
	1	9	9	12	13	19	23	38	58	B
	2	8	12	16	20	42	49	61	73	B
	2	9	18	25	31	59	68	76	84	B
	2	10	23	30	35	61	70	77	84	B
	2	11	26	32	35	55	62	69	79	B
	2	12	14	16	18	29	36	49	65	B
	2	13	36	42	47	76	89	95	97	B
	2	14	16	20	25	47	57	68	79	B
	3	6	12	14	17	31	39	52	67	B
	3	7	9	11	12	20	30	46	64	B
	3	8	8	10	12	23	29	43	61	B
	3	9	24	27	30	48	57	67	78	B
	3	10	23	26	29	47	57	68	79	B
	4	7	12	16	20	46	64	75	84	B
	4	8	19	25	30	60	80	89	94	B
	4	9	13	16	19	48	64	74	83	B
	4	10	14	20	23	49	69	80	80	B
	4	11	9	14	17	68	83	90	94	B
	4	12	16	21	24	47	65	77	86	B
	5	6	17	20	25	48	66	78	86	B
	5	7	17	22	25	48	64	76	85	B
	5	8	10	18	22	56	83	93	98	B
	5	9	24	31	34	62	85	94	98	B
	5	10	18	25	28	58	85	95	98	B
	6	6	30	36	39	67	87	95	98	B
	6	7	14	20	23	46	59	70	80	B
	6	8	13	18	21	42	57	70	81	B
	6	9	22	30	34	64	87	95	98	B
	6	10	17	23	25	45	60	71	81	B
	7	6	22	25	29	48	61	72	82	B
	7	7	11	13	15	24	29	40	58	B
	7	8	17	20	23	39	51	64	76	B
	7	9	10	13	15	26	31	45	63	B
	7	10	12	15	17	30	39	53	68	B
169**	2	2		62	70	88	97	99	100	B
252**	1	1		27	34	50	53	53	63	C
EPA-68-	D AVE***		20	33	36	40	51	62	74	B
02-3271	E AVE***		17	28	32	40	50	60	70	B
A RANK DATA AVERAGE			39	70	78	92	96	97	98	
B RANK DATA AVERAGE			17	24	27	44	56	67	77	
C RANK DATA AVERAGE				27	34	50	53	53	63	
A+B RANK DATA AVERAGE			20	31	35	51	62	71	81	
B+C RANK DATA AVERAGE			17	24	28	45	57	68	79	
A+B+C RANK DATA AVERAGE			20	30	35	51	62	71	80	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

**MECHANICAL COLLECTOR UPSTREAM OF SCRUBBER

***AVERAGE OF 6 SAMPLES FOR D, 8 SAMPLES FOR E. ESP UPSTREAM OF SCRUBBER.

TABLE 7. PARTICLE SIZE DISTRIBUTION DATA FOR ESP CONTROLLED DRY BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE#	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
29	1	5	22	36	43	64	75	81	88	A
	1	7	16	28	34	53	75	93	99	A
	2	5	23	39	46	67	85	93	97	A
	2	7	27	45	57	84	93	94	96	A
	3	5	26	46	55	76	88	93	97	A
	3	7	30	53	63	88	95	98	99	A
81	1	5		16	24	42	68	83	90	B
	1	6		6	10	22	47	72	84	B
	1	7		6	10	20	43	60	78	B
	1	8		7	11	24	42	54	70	B
	2	7		8	12	28	51	64	76	B
	2	8		14	19	44	74	83	97	B
	2	9		6	9	24	56	75	87	B
	2	10		15	19	34	58	72	83	B
	3	4		3	5	14	53	68	79	B
	3	5		2	6	19	48	63	78	B
	3	6		6	9	21	46	69	80	B
	3	7		17	21	35	57	66	78	B
115	1	5	4	11	15	27	52	67	78	B
	1	6		6	8	16	27	37	47	B
	1	7	2	7	10	22	48	61	73	B
129	5	1		5	11	29	50	63	75	C
	6	1		8	13	28	44	56	69	C
	9	1		7	9	20	35	49	63	C
	10	1		3	7	23	47	61	75	C
	12	2		78	81	91	94	95	97	C
	13	1		80	84	94	95	95	96	C
172**	1	1		5	5	6	13	18	37	C
173**	1	1		9	15	31	36	45	58	C
250	1	1		4	4	12	23	34	46	B
	1	2		5	9	25	36	47	58	B
	1	3		4	8	24	38	55	68	B
	2	1		2	3	9	33	73	95	B
	2	2		5	6	15	36	62	80	B
	2	3	1	5	9	21	43	73	90	B
	3	1	5	8	11	23	68	92	99	B
	3	2	1	5	8	12	45	67	83	B
	3	3		1	3	12	26	44	62	B
	4	1				3	17	34	58	B
	4	2		2	3	10	30	63	84	B
	5	1		2	2	10	25	54	74	B
	5	2		1	2	8	23	50	70	B
	5	3		2	3	10	24	41	55	B
	6	1	0	0	0	0	2	4	13	C
	6	2		12	16	22	43	73	91	B
	6	3		1	3	13	33	61	80	B
	7	1	1	2	2	8	23	43	59	B
	7	2	0	1	2	8	26	50	68	B
	7	3		1	3	10	26	55	76	B
	8	1		2	2	8	28	59	79	B
	8	2		2	2	9	28	54	73	B
	8	3		2	3	12	33	62	80	B
	9	1		1	2	8	27	46	62	B
	9	2		3	4	13	37	63	81	B
	9	3		2	3	10	27	54	74	B
	10	1		2	2	8	24	50	68	B
	10	2		3	4	15	44	75	93	B
	10	3		3	5	16	38	67	85	B

(continued)

TABLE 7. (continued)

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
	11	1		2	3	8	17	39	56	B
	11	2		2	3	13	30	54	70	B
	11	3		1	3	20	43	68	89	B
	12	1		1	2	6	14	30	45	B
	12	2		1	2	7	19	47	69	B
	12	3		1	3	13	33	55	73	B
	13	1		2	2	9	23	51	70	B
	13	2		1	2	8	22	48	66	B
	13	3				6	20	53	79	B
267	4	1	11	15	16	36	81	89	95	A
EPA-68-02-3271	A AVE***		3	5	8	18	38	57	71	B
	B AVE***		8	14	18	32	52	64	74	B
	C AVE***		5	8	10	15	27	37	47	B
OHIO-EDISON	ED13	1	23	35	42	64	91	100	100	B
	ED13	2	13	25	32	52	79	95	99	B
	ED13	3	7	12	15	30	65	88	98	B
	ED13	4	22	32	38	59	88	98	100	B
	G025	3A	17	26	32	52	76	90	95	B
	G025	3B	18	24	28	41	59	74	84	B
	G025	4A	17	25	30	49	72	93	99	B
	G025	4B	18	24	28	40	58	68	73	B
	G025	1A	11	15	17	27	41	51	60	B
	G025	1B	22	33	40	60	81	92	96	B
	G025	2A	16	25	29	45	67	77	87	B
	G025	2B	22	32	37	54	74	85	90	B
	G025	1A	12	21	25	42	65	86	95	B
	G025	1B	13	23	30	49	74	90	97	B
	G025	2A	12	22	27	44	71	84	91	B
	G025	2B	16	25	30	44	70	89	96	B
	G026	1A	13	23	28	43	67	85	95	B
	G026	1B	12	21	27	37	58	82	94	B
	G026	2A	16	23	27	43	66	82	92	B
	G026	2B	9	13	15	22	35	44	51	B
	G026	1A	15	24	30	50	75	88	94	B
	G026	1B	20	30	35	53	74	89	95	B
	T011	1	29	44	52	73	97	100	100	B
	T011	2	29	41	48	68	86	99	100	B
	T011	3	27	37	43	60	89	99	100	B
	T011	4	26	38	44	63	87	100	100	B
	T009	1	10	19	25	40	76	95	99	B
	T009	2	24	30	35	54	81	92	96	B
	T009	3	16	28	34	55	82	97	100	B
	T009	5	27	40	47	67	93	99	100	B
	T010	1	12	21	24	37	67	86	93	B
	T010	2	15	21	24	39	70	87	92	B
A DATA AVERAGE			22	37	45	67	85	92	96	
B DATA AVERAGE			11	12	15	27	48	65	77	
C DATA AVERAGE			0	22	25	36	46	54	65	
A+B DATA AVERAGE			12	14	17	29	50	67	79	
B+C DATA AVERAGE			11	13	16	27	47	65	76	
A+B+C DATA AVERAGE			12	14	18	30	50	66	78	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

**MULTIPLE CYCLONES UPSTREAM OF ESP.

***AVERAGE OF 11 SAMPLES FOR A, 8 SAMPLES FOR B, AND 8 SAMPLES FOR C. NOTE THAT C HAS 2 ELECTROSTATIC PRECIPATORS IN SERIES.

TABLE 8. PARTICLE SIZE DISTRIBUTION DATA FOR BAGHOUSE CONTROLLED DRY BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRON S)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
OHIO-EDISON	SAM3	1	16	28	34	55	79	96	99	B
	SAM3	2	12	22	28	50	75	87	94	B
B RANK DATA AVERAGE			14	25	31	53	77	92	97	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 9. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED WET BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
64	1	1	3	5	7	26	41	44	46	B
	1	2	2	4	5	10	14	16	18	B
	2	1	2	4	5	26	43	50	57	B
B RANK DATA AVERAGE			2	4	6	21	33	37	40	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 10. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE CYCLONE CONTROLLED WET BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
264	1	1		19	31	61	84	93	99	C
C RANK DATA AVERAGE				19	31	61	84	93	99	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 11. PARTICLE SIZE DISTRIBUTION DATA FOR ESP CONTROLLED WET BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
174**	1	1		21	39	79	95	99	100	C
175	1	1		11	22	55	88	100	100	C
176	1	1		6	18	51	80	91	98	C
177	1	1		2	4	9	31	48	65	C
178	1	1		1	2	5	20	36	54	C
C RANK DATA AVERAGE				8	17	40	63	75	83	

*SEE TEXT FOR TEST SITE IDENTIFICATION.
**MECHANICAL COLLECTOR FOLLOWED BY ESP.

TABLE 12. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED CYCLONE FURNACES BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
171	1	2		0	0	0	8	13	33	D
D RANK DATA AVERAGE				0	0	0	8	13	33	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 13. PARTICLE SIZE DISTRIBUTION DATA FOR SCRUBBER CONTROLLED CYCLONE FURNACES BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
171	1	4		82	85	92	93	94	95	A
A RANK DATA AVERAGE				82	85	92	93	94	95	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 14. PARTICLE SIZE DISTRIBUTION DATA FOR ESP CONTROLLED CYCLONE FURNACES BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
179	1	1		2	2	10	33	49	66	C
180	1	1		25	31	48	69	80	89	C
181	1	1		11	15	27	47	61	74	C
182	1	1		32	38	54	71	80	88	B
183	1	1		17	24	42	61	71	81	B
B DATA RANK AVERAGE				25	31	48	66	76	85	
C DATA RANK AVERAGE				13	16	28	50	63	76	
B+C DATA RANK AVERAGE				17	22	36	56	68	80	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 15. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED SPREADER STOKER BOILERS BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
35	1	2			10	12	17	24	27	B
	2	2			3	4	8	12	22	B
	3	2				2	7	11	23	B
	4	2			1	1	4	7	21	B
	5	2			3	4	8	12	20	B
	6	2			3	4	12	27	37	B
	7	2				4	10	18	30	B
	8	2				7	13	19	33	B
	9	2				5	10	23	34	B
	10	2				3	8	15	29	B
	11	2			2	5	11	22	40	B
	12	2			8	13	20	26	35	B
	13	2			2	6	11	22	34	B
	14	2			1	4	11	17	26	B
	16	2			1	6	12	20	31	B
	17	2			1	4	11	19	33	B
	18	2			1	4	9	17	32	B
	19	2			3	7	12	19	31	B
	20	2			2	4	7	11	17	B
	21	2			4	7	15	20	28	B
	22	2			8	16	23	28	33	B
63	1	1	1	1	1	8	13	16	28	C
274	2	3		2	2	2	12	35	60	A
80-IBR	1	1	1	1	1	2	2	3	3	A
-12	1	2	4	4	5	5	7	9	10	A
82-IBR	1	1	1	1	1	1	2	4	6	A
-17	1	2	1	1	1	2	4	6	9	B
	1	3	1	3	4	7	12	14	15	A
	2	1	1	1	1	2	4	8	13	A
	2	2	3	4	4	6	12	18	24	A
	2	3	3	5	6	9	15	19	24	A
	3	1	3	3	4	5	8	12	16	A
	3	2	3	3	3	5	8	10	14	A
	3	3	1	2	2	4	8	11	14	A
82-IBR	1A	1	1	1	1	1	4	6	8	B
-18	2	1	4	10	13	30	59	73	84	B
	3	1	2	4	5	9	17	20	25	B
	4	1	8	12	13	17	27	29	31	B
	5	1	7	7	7	8	14	14		B
	6	1	2	3	3	6	14	17	20	B
	7	1	4	7	9	19	38	50	54	B
	8	1	7	13	15	19	30	34	37	B
	9	1	13	17	19	30	55	67	76	B
A RANK DATA AVERAGE			2	3	3	4	8	13	18	
B RANK DATA AVERAGE			5	8	5	8	16	23	32	
A+B RANK DATA AVERAGE			4	5	5	7	14	20	28	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 16. PARTICLE SIZE DISTRIBUTION DATA FOR BITUMINOUS COAL FUELED SPREADER STOKERS WITH MULTIPLE CYCLONES WITH FLYASH REINJECTION

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
242	6	2	1	2	2	8	51	73	86	C
C RANK DATA AVERAGE			1	2	2	8	51	73	86	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 3-17. PARTICLE SIZE DISTRIBUTION DATA FOR BITUMINOUS COAL FUELED SPREADER STOKERS WITH MULTIPLE CYCLONES WITHOUT FLYASH REINJECTION

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
80-IBR -12**	1	1	17	22	26	40	55	60	65	A
82-IBR -18**	1	1	8	11	12	19	47	67	80	B
	1A	1	13	17	20	28	58	65	68	A
	2	1	13	19	22	34	62	78	91	A
	3	1	12	20	21	32	62	78	88	A
	4	1	10	17	22	40	70	77	85	A
	5	1	2	2	3	9	26	39	51	A
	6	1	5	8	9	16	39	57	70	A
	7	1	6	11	13	28	54	70	80	B
	8	1	1	3	4	15	42	58	70	A
	9	1	7	14	17	30	57	73	81	A
A RANK DATA AVERAGE			9	14	16	27	52	65	74	
B RANK DATA AVERAGE			7	11	13	24	51	69	80	
A+B RANK DATA AVERAGE			9	13	15	26	52	66	75	

*SEE TEXT FOR TEST SITE IDENTIFICATION

**TWO STAGES OF MULTIPLE CYCLONES

TABLE 18. PARTICLE SIZE DISTRIBUTION DATA FOR ESP CONTROLLED SPREADER STOKERS BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
262**	1	1		41	46	61	82	90	97	C
C RANK DATA AVERAGE				41	46	61	82	90	97	

*SEE TEXT FOR TEST SITE IDENTIFICATION.
**MULTIPLE CYCLONES UPSTREAM OF ESP

TABLE 19. PARTICLE SIZE DISTRIBUTION DATA FOR BAGHOUSE CONTROLLED SPREADER STOKER BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA DATA
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
35	1	4		5	5	8	15	23	57	B
	2	4		1	1	3	16	35	62	B
	3	4		8	8	10	17	28	57	B
	4	4					3	16	49	B
	5	4		13	13	18	25	39	53	B
	6	4		12	12	13	17	32	62	B
	7	4		6	9	13	26	42	61	B
	8	4		2	3	10	18	24	50	B
	9	4		9	13	23	35	55	73	B
	10	4		3	6	15	28	40	66	B
	11	4		4	6	14	27	45	71	B
	12	4		88	89	89	90	91	94	B
	13	4		5	7	13	24	34	64	B
	14	4		58	59	62	67	74	83	B
	15	4		6	9	15	33	39	57	B
	16	4		8	11	19	34	48	68	B
	17	4		13	18	28	45	61	76	B
	18	4		93	93	94	95	96	98	B
	19	4		9	13	27	47	62	79	B
	20	4		15	18	26	41	55	74	B
	21	4		11	15	26	43	59	78	B
	22	3		5	8	16	30	47	67	B
36	1	1		9	10	19	41	58	69	A
	1	2		13	16	30	64	80	85	A
	2	1		8	10	21	41	53	57	A
	2	2		13	17	32	55	64	72	A
	3	1		20	26	33	61	73	78	A
	4	1		9	16	23	46	67	72	A
	5	1		6	9	15	44	56	67	A
37	1	1		13	13	18	31	38	42	A
	1	2		15	19	33	65	80	85	A
	2	1		3	4	13	32	52	71	A
	3	1		6	7	14	25	48	61	A
	4	1		20	23	30	49	62	67	A
	5	1		25	28	38	63	77	82	A
	6	1		11	16	30	61	77	82	A
38	1	1		45	49	53	65	73	78	A
	2	1		26	29	37	58	70	77	A
	3	1		25	27	38	59	72	80	A
	4	1		25	29	42	65	75	83	A
	5	1	18	24	27	35	55	66	73	A
39	1	1		3	5	14	39	55	58	A
	2	1	4	8	10	17	40	51	57	A
	3	1	5	7	10	19	52	72	78	A
	4	1	6	11	14	24	60	73	81	A
	5	1	5	10	14	24	57	76	80	A
	6	1	15	20	23	27	59	78	83	A
	7	1		10	16	24	51	69	74	A
	8	1	2	5	7	11	37	65	78	A
	9	1	4	10	15	22	52	78	93	A
	10	1	2	9	12	21	51	81	97	A
	11	1		7	13	22	50	65	68	A
40	1	1		11	16	29	53	65	71	A
	2	1	4	11	17	29	53	66	75	A
	3	1	6	15	20	34	54	62	66	A
	4	1	5	12	17	29	59	68	73	A
	5	1	8	15	20	33	56	65	71	A
	6	1	7	14	17	27	59	79	89	A
	7	1	8	15	18	29	58	76	87	A
A RANK DATA AVERAGE			7	14	17	27	52	67	75	
B RANK DATA AVERAGE				18	20	26	35	48	68	
A+B RANK DATA AVERAGE			7	15	18	26	46	60	72	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 20. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED OVERFEED STOKERS BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION TEST SITE*	 TEST NO.	 TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	 1.00	 1.25	 2.50	 6.00	 10.00	 15.00	DATA RANK
281	3	3		4	5	6	23	45	67	A
EPA-600	L2	AVE**	10	12	13	15	22	30	38	B
/7-81-020A	L4	AVE**	17	19	20	20	27	35	42	B
A RANK DATA AVERAGE				4	5	6	23	45	67	
B RANK DATA AVERAGE			14	16	17	18	25	33	40	
A+B RANK DATA AVERAGE			14***	12	13	14	24	37	49	

*SEE TEXT FOR TEST SITE IDENTIFICATION.
**TREATED AS ONE SAMPLE EACH.
***AVERAGE NOT USED DUE TO INCONSISTENCY IN REPORTING.

TABLE 21. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE CYCLONE CONTROLLED OVERFEED STOKERS BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION TEST SITE*	 TEST NO.	 TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	 1.00	 1.25	 2.50	 6.00	 10.00	 15.00	DATA RANK
251	1	1		81	82	85	92	95	98	B
EPA-600	L2	AVE**	11	13	14	17	22	29	35	B
/7-81-020A	L4	AVE**	20	22	22	27	33	40	47	B
		B AVER	16	39	39	43	49	55	60	

*SEE TEXT FOR TEST SITE IDENTIFICATION.
**TREATED AS ONE SAMPLE EACH.

TABLE 22. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED UNDERFEED STOKERS BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
EPA-600/7-81-020A	L1	AVE**	8	9	10	14	23	32	40	B
	L3	AVE**	4	5	6	7	12	19	28	B
	L3	AVE***	6	7	8	10	14	20	30	B
	L5	AVE***	29	31	31	35	42	52	60	B
	L6	AVE***	48	56	59	62	70	76	82	B
	L7	AVE**	15	16	16	20	33	46	58	B
B RANK DATA AVERAGE			18	21	22	25	32	41	50	

*SEE TEXT FOR TEST SITE IDENTIFICATION
**TREATED AS ONE SAMPLE EACH
***TREATED AS ONE SAMPLE EACH. STACK OUTLET WHICH INCLUDES EFFECT OF DUST SETTLING IN DUCTING AND STACK.

TABLE 23. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE CYCLONE CONTROLLED UNDERFEED STOKERS BURNING BITUMINOUS COAL

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
EPA-600/7-81-020A	L1	AVE**	20	22	25	30	45	61	71	B
	L7	AVE**	32	37	38	48	73	88	96	B
B RANK DATA AVERAGE			26	30	32	39	59	75	84	

*SEE TEXT FOR TEST SITE IDENTIFICATION
**TREATED AS ONE SAMPLE EACH

obtained each day at the multiple cyclone inlet and outlet using Brink BMS-11 impactors. Isokinetic values were not reported for any of the impactor runs.

Impactor size data without a reported isokinetic value was given a B-ranking.

TSN's 15, 16, and 57

These test series all were performed on the TVA-operated Shawnee unit no. 10 at the Shawnee Steam Plant in Paducah, Kentucky. This unit is a 540-GJ/hr (150-MW), dry-bottom boiler which fires pulverized bituminous coal. A portion of the exhaust stream passed through one of three liquid scrubbers.

TSN's 15 and 16 were performed to specifically evaluate the effectiveness of experimental scrubbers for removing particulates and SO_2 from the flue gas. This testing took place in May 1974. Inlet samplings of the scrubbers were performed using an unconventional sampling train for mass loading plus particle size distribution with a cyclone and Brink impactor. The outlet samplings were performed with a Brink impactor. The reported isokinetic values for the testing were all 100 percent. The scrubber outlets were reheated with a direct-fired oil heater upstream of the sampling point.

The developmental scrubbers may not be representative of scrubbers used by utilities and industry but were included due to limited data availability. Although not mentioned in FPEIS, the uncontrolled inlet samples neglect cyclone catch and are thus an unacceptable method, with a resultant D-quality rating. The outlets probably include some oil particles but were taken in a relatively acceptable manner and are thus A-quality.

TSN 57 was part of a separate study of the scrubber effectiveness. The tests occurred during January and February 1977. Loads varied from 360 to 544-GJ/hr (100 to 151 MW).

Inlet sampling was performed with Brink BMS-11 impactors, and particle size distributions in the outlet gases were determined with MRI Model 1502 impactors. Sampling flowrate isokinetic values were not reported.

The lack of reported isokinetic values reduced impactor data to B-quality. One data set was further downgraded to D-quality since the data varied too drastically from the average and an error in data handling was suspected.

TSN's 29 and 115

Meramec no. 1, operated by Union Electric Company in St. Louis, Missouri, was the emissions source for these two test series. This unit, a 450-GJ/hr (125-MW), dry-bottom boiler, fired pulverized bituminous coal. The only emission control device was an ESP.

Samplings for TSN 29 were performed during boiler loads of 79 and 96 percent during March 1975. Brink impactors sampled the ESP inlet, and Andersen impactors sampled the ESP outlet. Specific impactor models were not given. All runs were reportedly performed under 100 percent isokinetic conditions. The sizing data for TSN 29 are A-quality.

Test data reported in TSN 115 occurred during November 1974. These tests established baseline emissions to compare to later tests during waste plus coal cofiring. Boiler loads varied from 62 percent to 113 percent of design capacity. A modified Brink BMS-11 impactor was used for ESP inlet samplings. An Andersen Mark III was the sampling device for outlet samples. The FPEIS report did not report sampling flowrate isokinetic values. The lack of reported isokinetic values lowers the sizing data to B-quality.

TSN 35

This test series was performed on a 43-GJ/hr (12-MW) utility boiler, boiler no. 2 at the Nucla Station in Nucla, Colorado, operated by Colorado Ute Electric Association. The unit, a bituminous-coal-fired spreader stoker, controlled emissions with a fabric filter baghouse. The effectiveness of the baghouse was the focus of the study.

The testing spanned from September through October 1974. In all, there were 22 days of testing. On each day of testing, baghouse inlet and outlet emission samples were taken using EPA Method 5 to determine total loading and Andersen Mark III impactors to determine size distribution. No system operating conditions were included in FPEIS. Additionally, sampling flowrate isokinetic values were not recorded for the impactor runs.

Impactor data are considered reliable, but without a reported isokinetic value it generally cannot be ranked better than B-quality. A data set, test 15 sample 2, was deleted because its distribution varied drastically from others in TSN 35.

TSN's 36, 37, 38, 39, and 40

These five test series contain the data from a single study in 1974 to investigate the application of a fabric filter baghouse to an industrial boiler exhaust stream. The boiler was a bituminous-coal-fired spreader stoker operated by Kerr Industries in Concord, North Carolina.

Operating conditions were not specified for the boiler unit during any of the test runs. All samples were at the baghouse outlet. Andersen Mark III impactors were the samplng devices. All samplings reported 100 percent sampling flowrate isokinetic values. The methodology and conditions were acceptable for all these samplings, and the resultant data are considered A-quality.

TSN 63

A 54-GJ/hr (15-MW) industrial boiler was the source for these data. It was a spreader stoker in Illinois which fired bituminous coal. No emission controls were mentioned.

At 40 percent of design capacity, a single sampling was performed using a Brink BMS-11 impactor. A sampling flowrate isokinetic value was not included. The low load and the lack of such supporting information reduced the sizing data of this report to C-quality.

TSN 64

This test series had as its emission source a wet-bottom boiler unit which fired pulverized bituminous coal. Although listed as "industrial," the unit tested was actually L. D. Wright no. 7 in Fremont, Nebraska, which is operated by the Fremont Department of Utilities. The unit had both a mechanical collector and a fabric filter baghouse to process emissions.

The unit operating load was at 54 percent of design capacity when three samplings were taken. All three samplings were obtained using a Brink BMS-11 impactor located upstream of both emission control devices. Sampling conditions were mostly unrecorded. The information left unreported included the flowrate isokinetic value for each sampling run. Although impactor runs were reliable, the lack of important substantiating data reduces the results to B-quality.

TSN 81

The source of these test data was a dry-bottom utility boiler firing pulverized bituminous coal. This unit, boiler no. 4 at the Colbert Steam Plant in Florence, Alabama, processed emissions with an ESP prior to the stack.

Emissions testing was conducted during a 3-day period in January 1976. On the first emissions testing day, the operating load was a constant 576-GJ/hr (160-MW). A variance was detected on the second and third day. For these 2 days, the morning load was 576-GJ/hr (160 MW), but the afternoon load decreased to 403-GJ/hr (112 MW).

Samplings were conducted on both the inlet and outlet of the ESP. Inlet samples were obtained with a Brink BMS-11 impactor. Outlet samples were obtained by using an Andersen Mark III impactor. Of the 13 inlet samplings and 12 outlet samplings, only one test (an inlet run) reported a sampling flowrate isokinetic value. That value was 107 percent. Excluding flowrate isokinetic values the sampling conditions were otherwise reported in adequate detail.

The run which includes a reported flowrate isokinetic value within acceptable limits is considered A-quality. The lack of reported isokinetic values in the remaining impactor tests reduces the sizing data to B-quality.

TSN's 128 and 250

These test series comprise two separate studies on the same dry-bottom, pulverized-bituminous-coal-fired utility boiler. The boiler, the 3280-GJ/hr (910-MW) Bull Run no. 1 operated by the TVA in Clinton, Tennessee, used an ESP as the sole control device in both studies.

TSN 128 conducted during July 1974 includes no operating or control device condition data. Both ESP inlet and outlet samples were obtained with the use of impactors. The ESP inlet sampling device was a modified Brink impactor. The modification was not specified. ESP outlet sampling device was an Andersen Mark III impactor. Sampling flowrate isokinetic values were unreported for all tests. The lack of reported isokinetic values reduces the sizing data of TSN 128 to B-quality.

TSN 250 contains impactor data for the inlet and outlet of a mobile ESP installed for demonstration purposes. Brink BMS-11 impactors were used for inlet samples, and University of Washington Mark III and Andersen Mark III impactors were both used for outlet samples. Unit operating conditions were assumed to be normal.

The test series reports that inlet samples were obtained at an average isokinetic value of 33 percent. The report also states that inlet measurements were corrected for subisokinetic samplings. This gross departure from standard methodology impairs the ESP inlet data's reliability and reduces those results to C-quality. Due to the availability of higher quality data, the uncontrolled (ESP inlet) sample data was excluded. The ESP outlet data was downgraded to B-quality since the sampling flowrate isokinetic value was not reported. One outlet data set was further reduced to C-quality since it varied quite drastically from the other outlet data sets.

TSN 129

This test series had as its emissions source a 79-GJ/hr (22-MW), dry-bottom utility boiler firing pulverized bituminous coal. The source, boiler no. 1 at the Mitchell Power Station in rural Georgia, had two ESP's in series for emissions control.

Testing occurred during May and June 1977. Operating loads varied from 31 percent to 100 percent of design capacity. ESP inlet samplings were performed using both a SASS train with cyclones and a device denoted only as "other impactor" by the FPEIS listing. ESP outlet samples were obtained by means of a SASS train with cyclones only. The FPEIS listing did not clearly indicate whether the outlet sample point was downstream of both ESP's or only the first. Isokinetic values were not given for any sampling. Most other sampling conditions were also left unreported.

SASS train sizing data are considered C-quality due to the methodology and lack of substantiating data. For the impactor runs, the resultant sizing data are considered B-quality, except those runs during which the operating loads fell below 35 percent. These low-load test results were considered C-quality.

TSN 130

This test series had as its source a 1310-GJ/hr (364-MW) dry-bottom utility boiler firing pulverized bituminous coal. The unit, located in Colstrip, Montana, was operated by the Montana Power Company. The test series assessed the effectiveness of a novel variable-throat venturi scrubber as the sole particulate emissions control device.

Scrubber inlet and outlet samples were obtained while the boiler operated at 90 percent to 98 percent capacity over a 4-day period (May 17 through 20, 1977). A Brink model BMS-11 impactor was used for all scrubber inlet (uncontrolled) samples. A University of Washington Mark III impactor was used for all scrubber outlet samples. Sampling flowrate isokinetic values were left unreported for all impactor samplings. Though all these data are impactor generated, the lack of reported isokinetic values reduces the reliability to B-quality.

TSN 169

These data were reported from tests on boiler no. 4 at the Firestone Tire & Rubber plant in Pottstown, Pennsylvania. This is a dry-bottom boiler which fires pulverized bituminous coal. All exhaust gases passed through multiple cyclones, and then part of the exhaust was further treated in a pilot FMC double alkali flue gas desulfurization liquid scrubber system.

Testing took place on September 29, 1977, with the unit operating continuously at 97.5 percent of capacity. Samplings were obtained between the multiple cyclones and scrubber plus downstream of the scrubber.

The first sample was obtained by polarized light microscopy. This methodology is considered unsound. There was a multiple cyclone malfunction during the test; thus, the resultant data are D-quality.

The second sample was obtained by an Andersen impactor at 110 percent of sampling flowrate isokinetic value but reported in a SASS format. Since the specific impactor model and primary data were not reported, the resultant data are considered B-quality.

TSN 171

This test series came from data from testing on La Cygne no. 1 operated by Kansas City Power & Light. This boiler was built by Babcock & Wilcox and rated at 3150-GJ/hr (875-MW). The furnace was of the cyclone class and fired bituminous coal. Emissions passed through one of eight two-stage venturi-absorption liquid scrubbers.

Testing took place April 18, 1978. The electrical output was reported operating continuously at 87 percent of design capacity. One uncontrolled particulate emissions sample and one controlled particulate emissions sample were obtained.

Due to high particulate concentrations at the uncontrolled sampling point, an impactor could not be used. Instead, polarized light microscopy was used. For the purposes of evaluation, this technique is not considered a sound methodology and is therefore D-quality.

The scrubber-controlled sample was obtained by use of an MRI impactor (model unreported) with a sampling flow of 99 percent of isokinetic flow. The use of sound methodology with acceptable conditions makes these data A-quality.

TSN 172

This test emission source was a 328-GJ/hr (91-MW) Babcock & Wilcox pulverized bituminous-coal-fired, dry-bottom utility boiler located in Delaware. Particulate emissions were controlled by a mechanical collector and ESP.

Testing took place on October 9, 1977. Operating conditions were normal with electrical output at 104 percent of design capacity. A SASS train with cyclones was used to obtain a single sample downstream of both control devices. The sampling flowrate isokinetic value of the test was not reported.

SASS train data that lacks a reported sampling flowrate isokinetic value are considered C-quality.

TSN 173

Source data for this test series reported that the emission source was a Babcock & Wilcox 328-GJ/hr (91-MW), dry-bottom utility boiler in Delaware fueled with pulverized bituminous coal. Source emissions passed through a multiple cyclone collector followed by an ESP.

Sampling took place on November 10, 1977 with electrical output at 85 percent of design capacity. A single SASS train with cyclone samples was extracted downstream of the multiple cyclones and ESP. The sampling flowrate isokinetic value was not reported. SASS train data without a reported sampling flowrate isokinetic value are considered C-qualty.

TSN 174

This report is one of a series for wet-bottom boiler units firing pulverized bituminous coal. In this case, the unit was a 460-GJ/hr (128-MW) Combustion Engineering utilty boiler in South Carolina. For emission control, this unit had a multiple cyclone followed by an ESP.

Operating conditions on test date, January 7, 1978, were normal. Unit output was at 87 percent of design capacity. The test date was January 7, 1978. A single stack sampling was performed downstream of the ESP using a SASS train with cyclones. The sampling flowrate isokinetic value was not reported. The less reliable nature of a SASS train plus the lack of a reported sampling flowrate isokinetic value makes the size data for this test series C-quality.

TSN 175

This test series documents testing performed on a 522-GJ/hr (145-MW), pulverized-bituminous-coal-fired, wet-bottom utility boiler manufactured by Combustion Engineering and located in South Carolina. An ESP served as the emissions control device.

A single size sampling was conducted on June 1, 1978 with operating conditions reported as normal. Power production was at 93 percent of design capacity. The sampling point was downstream of the ESP. Sampling conditions were sparsely documented. No sampling flowrate isokinetic value was reported for the sample obtained with a SASS train with cyclones. SASS train data without a reported sampling flowrate isokinetic value are considered C-quality.

TSN 176

Test series number 176 documents testing performed on a 493-GJ/hr (137-MW), pulverized-bituminous-coal-fired, wet-bottom utility boiler manufactured by Combustion Engineering and located in South Carolina. An ESP served as the emissions control.

A single size sampling was conducted on June 2, 1978 with operating conditions reported as normal. Power production was at 95 percent of design capacity. The sampling point was downstream of the ESP. The sampling device was a SASS train with cyclones, sampling conditions were sparsely documented, and no sampling flowrate isokinetic value was reported.

Sampling with a SASS train, compounded by the lack of reported sampling flowrate isokinetic value, reduces the data to C-quality.

TSN 177

This test series had as its source a 1300-GJ/hr (360-MW), pulverized-bituminous-coal-fired, wet-bottom utility boiler located in South Carolina. An ESP served as the sole emission control device.

On September 18, 1978, as the unit operated at 100 percent of design capacity, a single ESP-controlled emission sampling occurred using a SASS train with cyclones. The sampling flowrate isokinetic value was not reported. SASS train data without any documented sampling flowrate isokinetic value cannot be considered better than C-quality.

TSN 178

This test series had as its source a 1300-GJ/hr (360-MW), pulverized-bituminous-coal-fired, wet-bottom utility boiler located in South Carolina. An ESP served as the sole emission control device.

On September 26, 1978, as the unit operated at 100 percent of design capacity, a single ESP-controlled sampling occurred using a SASS train with cyclones. The sampling flowrate isokinetic value was not reported. SASS train data without any documented sampling flowrate isokinetic value cannot be considered better than C-quality.

TSN 179

A 2315-GJ/hr (643-MW) Babcock & Wilcox utility boiler located in Illinois was the source for this test series. The unit contained a cyclone furnace fueled with bituminous coal. An ESP controlled the emissions.

A single ESP-controlled particle sampling was performed on May 30, 1978 with the boiler operating under normal conditions at 68 percent of design capacity. The sampling was performed using a SASS train with cyclones. The sampling flowrate isokinetic value was not reported. SASS train data without a documented sampling flowrate isokinetic value cannot be considered better than C-quality.

TSN 180

A 1300-GJ/hr (360-MW) utility boiler was the source for this test series. The unit contained a Babcock & Wilcox cyclone furnace fueled with bituminous coal. An ESP controlled the emissions.

A single ESP-controlled sampling was performed on April 30, 1978. The boiler operated under normal conditions at 70 percent of design capacity. The sampling was performed with a SASS train with cyclones. The sampling flowrate isokinetic value was not reported. SASS train data without any documented sampling flowrate isokinetic value cannot be considered as better than C-quality.

TSN 181

A 2315-GJ/hr (643-MW) Babcock & Wilcox utility boiler located in Illinois was the source for this test series. The unit contained a cyclone furnace fueled with bituminous coal. An ESP controlled the emissions.

A single ESP-controlled sampling was performed on May 9, 1978 with the boiler operating under normal conditions at 70 percent of design capacity. The sampling was performed with a SASS train with cyclones. The sampling flowrate isokinetic value was not reported. SASS train data without documented sampling flowrate isokinetic value cannot be considered better than C-quality.

TSN 182

This test series was conducted on a 486-GJ/hr (135-MW) utility boiler located in Ohio. The unit contained a cyclone furnace fueled with bituminous coal. Emissions were controlled by an ESP.

A single sampling was performed on August 14, 1978, as the unit operated at 88 percent of design capacity under normal conditions. A SASS train with cyclones was used as the sampling device. The sampling location was downstream of the ESP and achieved 93 percent of sampling flowrate isokinetic value. The use of a SASS train for sampling makes the resultant data B-quality.

TSN 183

This test series came from sampling on a 486-GJ/hr (135-MW) utility boiler located in Ohio. The unit contained a cyclone furnace fueled with bituminous coal with emissions controlled by an ESP.

A single sampling was performed on August 16, 1978, with the unit operating at 88 percent of design capacity under normal conditions. A SASS train with cyclones was used as the sampling device. The sampling point was downstream of the ESP and achieved 95 percent of sampling flowrate isokinetic value. The use of a SASS train for sampling makes the resultant data B-quality.

TSN 242

These test data came from testing at Site A in the EPA tests on industrial stokers. Site A was an 317-GJ/hr (88-MW) Foster Wheeler boiler fueled with bituminous coal fed by a Detroit Stoker spreader stoker with traveling grate. Emissions passed through multiple cyclones with flyash reinjection, then to an ESP followed by a liquid scrubber.

While most of the data are simply EPA Method 5 runs, on August 26, 1977, a single particle size distribution sampling was performed. The boiler was operated at 74 percent of design capacity as a Brink Model B impactor sampled emissions at the multiple cyclones outlet. The sampling flowrate isokinetic value of 113 percent was beyond the acceptable limit. In addition, the FPEIS report notes that the catch of the impactor was limited to particle sizes between 0.3 and 3.0 microns, which accounted for less than 6 percent of the total catch. Given the limiting conditions under which the size data were obtained, the rating is C-quality.

TSN 248

A 148-GJ/hr (41-MW) boiler of the commercial/institutional class served as the source for this test series. The unit, a dry-bottom wall-fired boiler, was fueled with bituminous coal. No emission controls were in use.

Testing was performed on February 27, 1978, as the unit operated at 79 percent of design capacity. This load was indicated to be the normal maximum operating load. A single particle sizing sample was drawn using a SASS train with cyclones. The sampling flowrate isokinetic value was reported to be 92 percent. Though the conditions for this test are acceptable, the use of a SASS train with cyclones for particle size sampling reduced the particle data to B-quality.

TSN 251

TSN 251 comes from testing performed on a 15-GJ/hr (4-MW) overfeed stoker commercial/institutional boiler. Bituminous coal was fired, and emissions were controlled with a mechanical collector.

Testing took place March 13, 1979, as the unit operated continuously at 100 percent of design capacity. A SASS train with cyclones sampled downstream of the mechanical collector with a sampling flowrate isokinetic value of 99 percent. Though the conditions for this test are acceptable, the use of a SASS train with cyclones for sampling purposes reduces the particle data to B-quality.

TSN 252

A 92-GJ/hr (25-MW) commercial/institutional, dry-bottom, wall-fired boiler was the source for these reported data. The boiler was fueled with pulverized bituminous coal. Emission control was achieved with multiple cyclones and a liquid scrubber.

The boiler operated continuously at 94 percent of capacity as a single particle size distribution sampling was performed between the multiple cyclones and liquid scrubber. This particle size sampling was performed March 21, 1979, using a SASS train with cyclones. The reported sampling flowrate isokinetic value was 87 percent. These data, being SASS-train-sampled below the acceptable range for isokinetics, must be ranked as C-quality.

TSN 262

A 158-GJ/hr (44-MW) industrial spreader-stoker boiler firing bituminous coal was sampled to obtain the data for TSN 262. The boiler's emissions were controlled by both a mechanical collector and an ESP. This testing was part of a comprehensive survey of industrial combustion source emissions.

A single sampling was performed on February 8, 1979, as the boiler operated continuously at 91 percent of design capacity. The sampling device, a SASS train with cyclones, was placed downstream of the ESP. No sampling flowrate isokinetic value was reported.

SASS train data without a documented sampling flowrate isokinetic value cannot be considered better than C-quality.

TSN 264

A 185-GJ/hr (50-MW) industrial wet-bottom boiler firing pulverized bituminous coal was sampled to obtain the data for TSN 264. The only emission control was multiple cyclones. This testing was part of a comprehensive survey of emissions from industrial sources.

A single particle size sampling was performed on May 18, 1979, as the boiler operated continuously at 65 percent of design capacity. The sampling occurred downstream of the multiple cyclones using a SASS train with cyclones. The sampling flowrate isokinetic value was not reported. SASS train data without a documented sampling flowrate isokinetic value cannot be considered better than C-quality.

TSN 267

The emission source for this data set was a 1080-GJ/hr (300-MW) tangentially fired utility dry-bottom boiler fueled with pulverized bituminous coal. The effluent stream was treated by an ESP followed by a liquid scrubber.

Two particle size distribution tests were performed on 2 consecutive days in December 1979. An MRI 15-oz impactor was used to sample one ESP-controlled and one ESP-plus-scrubber-controlled emission sample each day.

On the first day, the boiler was fed coal at a rate of 78,810 kg/hr (173,740 lb/hr), and generated 806-GJ/hr (224-MW) of electricity. The sampling flowrate isokinetic value for the ESP-controlled sample was 126 percent, and the dually controlled sample had an isokinetic value of 77 percent.

The second day of impactor testing had a lower feed rate with 74,940 kg/hr (164,880 lb/hr) of bituminous coal being fired continuously. Sampling flowrate isokinetic values improved for the ESP-controlled sample but not for the ESP-scrubber sample. The values were 96 percent and 73 percent, respectively.

Only the ESP-controlled sample from the second day merits an A-quality ranking. The unacceptable isokinetic values from the other three impactor samples reduces their value to B-quality.

TSN 274

The source for this data set was designated Site E in the EPA testing series for industrial boilers. Site E was a 190-GJ/hr (53-MW) Riley boiler fueled with bituminous coal fed by a Riley traveling-grate spreader stoker. Emissions were controlled by multiple cyclones.

A single particle size distribution test was performed on December 20, 1978, using a Brink Model B impactor. The boiler was fueled at a rate of

6,585 kg/hr (14,520 lb/hr), generating steam at 69 percent of design capacity. The Brink impactor sampled uncontrolled emissions at 101 percent of the sampling flowrate isokinetic value. All devices and conditions are well within acceptable limits and hence these data are considered A-quality.

TSN 281

Data from Site K testing as part of EPA tests of industrial stoker boilers are contained in this test series. Site K was a 54-GJ/hr (15-MW) Riley bituminous-coal-fueled boiler with a Riley traveling grate overfeed stoker. Only multiple cyclones were in-line as an emissions control device.

A single size test was performed on November 9, 1979, using a Brink Model B impactor. The boiler operated at 102 percent of design capacity with a coal feedrate of 2,200 kg/hr (4,850 lb/hr). The sampling was upstream of the multiple cyclones at an unspecified sampling flowrate isokinetic value. Six EPA Method 5 tests were documented with sampling flowrate isokinetic values of approximately 102 percent. This single impactor test result is considered A-quality.

TSN 307

This test series is data from sampling at the Sora Paper Company in Middletown, Ohio. Investigation found that the tested unit was a dry-bottom boiler firing pulverized bituminous coal with a rated steam production capacity of 7 kg/s (55,000 lb/hr) of steam production. A mechanical collector and liquid scrubber were used for emission controls, but due to a restrictively small sample port on the scrubber outlet, particle size tests were only conducted on the mechanical collector inlet.

Four uncontrolled particle size tests were performed in April 1980. The prevailing operating conditions were not documented beyond noting that three tests occurred while the boiler operated normally and the fourth occurred during soot-blow. Samplings were done with an Andersen Mark III impactor with 1-min sampling periods. No sampling flowrate isokinetic values were recorded for the impactor tests, but seven EPA Method 5 tests run simultaneously reported isokinetic values between 100 and 107 percent. Despite the lack of operating and sampling conditions data, the impactor results are considered A-quality.

EMB Report 80-IBR-12 (Ref. 7)

The data in this report, prepared for EPA's Emission Measurement Branch, was from Andersen cascade impactor sampling across the two-stage multiple cyclones of a 9.5 kg/s (75,000 lb/hr) steam capacity bituminous-coal-fired spreader stoker with an economizer and multiple cyclones for particulate control. Flyash from the multiple cyclones was not reinjected. Boiler no. 3 is located at the DuPont Washington Works in Parkersburg, West Virginia.

Testing was performed on December 17, 1980, with the boiler at full steam production rate. The reported sampling flowrate isokinetic values ranged from a low of 103.7 percent to a high of 110.0 percent. Based on the acceptable documentation and sampling methodology, the data are rated A-quality.

EMB Report 82-IBR-17 (Ref. 8)

Boiler no. 2 at the General Motors Corporation, Fisher Body Division Plant in Lansing, Michigan, was sampled during April 19 to 24, 1982, using an Anderson cascade impactor. The spreader stoker fed traveling grate boiler uses an economizer, multiple cyclones, and a baghouse to control particulate emissions. The baghouse was not sized for full flow, so a portion of the flue gas from the multiple cyclones is discharged into the exhaust stack. Flyash from the multiple cyclones was not reinjected. Although nameplate-rated at 22.7 kg/s (180,000 lb/hr) of steam, the boiler was operated at one-third, one-half, and two-thirds capacity.

Particle size sampling was conducted at the multiple cyclones inlet, baghouse inlet, and stack. The stack sample was not used, since it represents a mixture of two flow streams. Except for one inlet sample with a sampling flowrate isokinetic value of 122.3 percent, all sampling data were A-quality.

EMB Report 82-IBR-18 (Ref. 9)

Boiler no. 6 at the Burlington Industries, Inc. plant in Clarksville, Virginia, was tested for emissions July 12 to 16, 1982, using Anderson cascade impactors. Coal was fed into the combustion chamber by flippers onto a traveling grate, where overfire jets provided air to aid combustion. Two sets of multiple cyclones were used for emissions control. Although nameplate-rated at 18.9 kg/s (150,000 lb/hr) of steam, the boiler normally is operated under varying load conditions and was operated at full load, two-thirds load, and one-third load during the sampling.

Sampling was conducted across the dust collectors. The inlet impactor samples were excessively loaded on the first-stage impactor plate and the sampling location was too close to upstream and downstream flow disturbances. Inlet sample 1 was not included in the report, and inlet sample 2 was conducted at 126 percent sampling flowrate isokinetic value. Except as noted, the methodology and documentation are adequate and allow the data to be ranked as B-quality.

The outlet impactor samples were taken with acceptable methodology and documentation, except that outlet samples 1 and 7 were taken at about 80 percent sampling flowrate isokinetic value. Outlet samples 1 and 7 were downgraded to a B-quality ranking, while the remaining samples were given an A-quality ranking.

EPA 68-02-3271 (Ref. 10)

"Emission Characterization of Major Fosil Fuel Power Plants in the Ohio River Valley" was prepared by PEDCo Environmental, Inc. under EPA contract no. 68-02-3271. Averaged data was presented for five different powerplants in the area. The powerplants were not specifically identified in the report but were listed as plants A, B, C, D, and E. All particle size distributions were obtained using an Anderson 2000 Mark III in-stack cascade impactor with all eight stages plus a glass fiber backup filter. All particle size samples were obtained at a single sampling point located in the stack at a point of average velocity.

Plant A with a rated nameplate generating capacity of 2016-GJ/hr (560-MW) was placed into service in 1970. This Babcock & Wilcox unit has an opposed-fired burner configuration and is equipped with a Buell-weighted wire ESP to control particulate emissions. Plant A is probably the Dayton Power & Light Company's unit no. 2 at the J. M. Stuart Plant in Adams County, Ohio. Testing was conducted from March 4 to 11, 1980. Nominal power output was 2124 to 2178-GJ/hr (590 to 605-MW), but for one run the power output was approximately 1692-GJ/hr (470-MW). All sampling was conducted downstream of the ESP.

Eleven particle size distribution samples were taken using an Andersen Mark III in-stack cascade impactor and eleven total loading samples were taken using EPA Method 5. The report does not provide the data for each size distribution sample but only provides an average. Plant operating data, however, was presented. Due to the lack of sampling details, the average distribution is only ranked as B-quality.

Plant B has a rated nameplate generating capacity of 450-GJ/hr (125-MW) and was placed into service in 1954. This Babcock & Wilcox unit has a front-fired burner configuration and is equipped with a retrofit Research Cottrell ESP installed in 1973 to control particulate emissions. Plant B is probably Cincinnati Gas and Electric Company unit no. 3 at the Walter C. Beckjord Plant in Clermont County, Ohio. Testing was conducted from April 7 through 15, 1980.

Nominal power output was 306 to 410-GJ/hr (85 to 114-MW) with one excursion to 486-GJ/hr (135-MW). All sampling was downstream of the ESP.

Eight particle size distribution samples and eight EPA Method 5 samples were taken. As with site A, sampling was not adequately documented and only a particle size distribution average was reported. As with Plant A, the average distribution is downgraded to B-quality.

Plant C has a rated nameplate generating capacity of 587-GJ/hr (163-MW) and was placed into service in 1958. This Combustion Engineering unit has a tangential-fired burner configuration. The particulate emission control system consists of two ESP's in series. The newer retrofit Research Cottrell ESP was installed in 1975. Plant C is probably Cincinnati Gas and Electric Company unit no. 4 at the Walter C. Beckjord Plant in Clermont County, Ohio. Testing was conducted from April 17 through 23, 1980. Nominal power output was 511 to 583-GJ/hr (142 to 162 MW), although one excursion to 468-GJ/hr (130-MW) was recorded. All sampling was downstream of the two ESP's.

Eight particle size distribution samples and ten EPA Method 5 samples were taken. As with site A, sampling was not adequately documented and only a particle size distribution average was reported. As with Plant A, the average distribution is downgraded to B-quality.

Plant D has a rated nameplate generating capacity of 1480-GJ/hr (411-MW) and was placed into service in 1978. This Babcock & Wilcox unit has an opposed-fired burner configuration. The air pollution control equipment consists of an American Air Filter (AAF) rigid frame ESP that was installed in 1978. After passing through the ESP, the flue gas enters a carbide lime mobile bed flue gas desulfurization (FGD) system, which was also installed in 1978 by AAF.

Plant D is probably Louisville Gas and Electric Company unit no. 3 at the Mill Creek Plant in Dallam County, Kentucky. Testing was conducted from August 5 through 12, 1980. Nominal power outputs were 1152 to 1440-GJ/hr (320 to 400-MW) although loads of 634, 637, and 1012-GJ/hr (176, 177, and 281-MW) were recorded. All sampling was downstream of the FGD system.

Six particle size distribution samples and ten EPA Method 5 samples were taken. As with site A, sampling was not adequately documented and only a particle size distribution average was reported. As with Plant A, the average distribution is downgraded to B-quality.

Plant E has a rated nameplate generating capacity of 562-GJ/hr (156-MW) and was placed into service in 1962. This Combustion Engineering unit has a horizontal-fired burner configuration. The air pollution control equipment consists of a Research Cottrell weighted wire ESP installed in 1962. After passing through the ESP, the flue gas enters an AAF lime slurry FGD system, which was installed in 1976.

Plant E is probably Louisville Gas and Electric Company unit no. 4 at the Care Run Plant in Dallam County, Kentucky. Testing was conducted from August 18 through 22, 1980. Nominal boiler loads were 518 to 630-GJ/hr (144 to 175-MW). All sampling was downstream of the FGD system.

Seven particle size distribution samples and ten EPA Method 5 samples were taken. As with site A, sampling was not adequately documented and only a particle size distribution average was reported. As with Plant A, the average distribution is downgraded to B-quality.

EPA 600/7-81-020A (Ref. 11)

EPA 600/7-81-020A is a report entitled "Field Tests of Industrial Stoker Coal-Fired Boilers for Emissions Control and Efficiency Improvement -- Sites L1 through L7." The report summarizes test results for seven small institutional-type, stoker-fired boilers. Site location was not disclosed in the report. The test sites and test conditions are described in Table 24. Particle size distributions were taken at boiler outlet and in the stack for all sites except that boiler outlet samples were not taken at sites L5 and L6. In the cases of sites L3, L5, and L6, however, their stack

TABLE 24. TEST SITES AND TEST CONDITIONS

Test site	Stoker type	Peak steaming capacity kg/s (lb/hr)	Operating rate in percent of maximum capacity	Particulate emission control device	Year built
L1	Underfeed (multiple retort)	4.4 (34,500)	75	Multiple cyclones	1966
L2	Overfeed (vibrating grate)	5.1 (40,000)	85	Multiple cyclones	1960
L3	Underfeed (single retort)	3.9 (31,000)	60	None	1951
L4	Overfeed (traveling grate)	3.8 (30,000)	78	Multiple cyclones	1969
L5	Underfeed (multiple retort)	4.8 (38,000)	55	None	1950
L6	Underfeed (multiple retort)	3.4 (27,000)	65	None	1957
L7	Underfeed (multiple retort)	7.0 (55,000)	50	Multiple cyclones	1968

samples are considered to be for uncontrolled emissions since there is no installed particulate control device.

No primary or reduced data sets were presented in the report. Instead, averages were graphically presented for each site. An Andersen Mark III cascade impactor was used for size distribution sampling as well as a Bahco classifier. However, the Bahco classifier averages were not used in this report since the Bahco classifier does not use the preferred methodology for size distribution determination. Although the lack of sampling data downgrades the data, the average values presented warrant a rank of B-quality. Data are presented but not used for emission factor development for underfeed stokers with multiple cyclone controls burning bituminous coal from sites L1 and L7. Uncontrolled emissions (i.e., emissions into the control device) appear to be approximately double average uncontrolled emissions. More data is needed from other sites to substantiate or repudiate this data since it results in controlled particulate emissions for particle sizes less than 15 µm exceeding uncontrolled emissions at other sites.

Ohio Edison Company (Ref. 12)

Ohio Edison Company provided particle size data from several of its powerplants. All particle size distribution samples were taken with Andersen eight-stage cascade impactors.

Sammis unit no. 3 (SAM3) is a Babcock & Wilcox 666-GJ/hr (185-MW), pulverized-coal-fired, dry-bottom unit located in Jefferson County, Ohio. The outlets of its American Air Filter baghouse were sampled on November 11, 1982. The boiler was generating 107 kg/s (850,000 lb/hr) of steam while consuming 12.1 kg/s (95,718 lb/hr) of coal.

Edgewater unit no. 13 (ED13) is a Babcock & Wilcox 378-GJ/hr (105-MW), pulverized-coal-fired, dry-bottom unit located in Lorain County, Ohio. The outlet of its six-field ESP was sampled on April 27 and 28, 1982. The boiler was generating nominally 106 kg/s (840,000 lb/hr) of steam while consuming 13.1 kg/s (104,000 lb/hr) of coal.

Gorge unit no. 25 (GO25) is a Babcock & Wilcox 158-GJ/hr (44-MW), pulverized-coal-fired, dry-bottom unit located in Summit County, Ohio. The outlet of its Western three-field ESP was sampled on May 14 and 20, 1982 as well as October 21, 1982.

The boiler was generating nominally 52 to 59 kg/s (410,000 to 470,000 lb/hr) of steam while consuming 5.2 to 6.3 kg/s (41,000 to 50,000 lb/hr) of coal.

Gorge unit no. 26 (GO26) is a Babcock & Wilcox 158-GJ/hr (44-MW), pulverized-coal-fired, dry-bottom unit located near GO25. The outlet of its Western three-field ESP was sampled on May 13 and 20, 1982. At that time, the unit was producing 57 kg/s (450,000 lb/hr) and 81 kg/s (640,000 lb/hr) of steam, respectively, while consuming approximately 5.7 kg/s (45,000 lb/hr) and 6.4 kg/s (51,000 lb/hr) of coal, respectively.

Toronto unit no. 9 (T09) is another Babcock & Wilcox 158-GJ/hr (44-MW), pulverized-coal-fired, dry-bottom unit and is located in Jefferson County, Ohio. A four-field Buell ESP was installed in 1970. Outlet samples supplied by Ohio Edison Company were obtained on January 13 and 14, 1983 while 53 kg/s (420,000 lb/hr) of steam was being produced and nominally 6.6 kg/s (52,700 lb/hr) of coal was being consumed.

Toronto unit nos. 10 and 11 (T010 and T011) are identical Babcock & Wilcox 238-GJ/hr (66-MW), pulverized-wall-fired, dry-bottom units that have been in operation since 1949 at the Toronto Powerplant in Jefferson County, Ohio. Each received a four-field Buell ESP in 1970. The Ohio Edison Company provided ESP outlet particle size data for unit no. 10 for testing conducted on May 7, 1981 and for unit no. 11 for testing on August 10, 1982. Unit no. 10 produced 80 kg/s (636,000 lb/hr) of steam while consuming 11.8 kg/s (94,000 lb/hr) of coal. Unit no. 11 produced 81 kg/s (640,000 lb/hr) of steam while consuming 10.4 kg/s (82,500 lb/hr).

All Ohio Edison Company particle size distribution data sets presented sampling flowrates, tare, final, and net weights of the eight Andersen impactor plates plus filter, plus the calculated size distribution as a function of collected weight and particle size. No mention is made of sampling flowrate isokinetic values nor are they possible to calculate based on the limited data provided. Due to this short fall, all the data can only be considered B-quality.

3.3.2 Anthracite Coal

Cumulative size-specific particle size distribution data for each emission source and control device for anthracite coal combustion are listed in Tables 25 through 27. The tables also include an assigned rating for each data set.

The FPEIS data base managed by the Environmental Protection Agency was extensively used to provide data sets for this study. A discussion of these data sets follows. The FPEIS data sets are listed numerically by their test series number (TSN). Additional references outside of the FPEIS data were not discovered.

TSN'S 11, 73, 74, 75, 98, 99, 100, 101, 102, and 103

Three separate studies are documented by these test series; the combustion source, Boiler 1A at the Sunbury Steam Electric Station located in Shamokin Dam, Pennsylvania is the same for all three. The utility boilers operated by Pennsylvania Power & Light. The studies each measured the effectiveness of fabric filter baghouses which controlled emissions that first passed through multiple cyclones. An important point is that this unit fired a mixed fuel. Pulverized anthracite slit, anthracite no. 5 buckwheat, and petroleum coke were fed in varying proportions. Normal operation specified an 80 percent anthracite coal to 20 percent petroleum coke ratio. The anthracite factor went as high as 85 percent and as low as 42 percent. Due to the limited availability of data from anthracite-only fueled boilers,

TABLE 25. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE CYCLONE CONTROLLED DRY BOTTOM BOILERS BURNING ANTHRACITE COAL (WITH PETROLEUM COKE)

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE#	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
11	1	1	46	49	52	68	86	92	96	A
	2	1	8	12	16	23	40	56	69	A
73	1	1	20	25	28	38	51	53	55	A
	2	1	3	7	10	22	45	57	66	A
	2	2	3	8	11	22	49	66	75	A
	3	1	3	6	9	22	49	65	72	A
	3	2	2	3	5	17	45	59	67	A
	4	1	11	14	17	30	48	53	53	A
	4	2	3	5	8	17	34	40	54	A
	5	1	1	3	6	19	53	71	80	A
	5	2	4	8	11	22	55	71	80	A
	6	1	13	18	21	33	53	64	71	A
	6	2	9	13	17	32	65	79	84	A
	7	1	6	7	9	16	27	36	41	A
	7	2	10	13	15	29	59	7	83	A
	8	1	7	10	12	26	59	69	73	A
	8	2	5	7	8	16	56	69	71	A
	9	1	11	14	18	31	61	72	77	A
	9	2	4	7	10	22	55	73	77	A
	10	1	9	14	18	32	62	76	84	A
	10	2	9	14	18	33	60	74	83	A
74	1	1	4	5	5	20	38	49	58	A
	1	2		2	4	14	32	44	53	A
	2	1	5	7	9	20	45	57	64	A
	2	2	5	6	8	16	29	49	79	A
	3	1	9	11	13	22	34	47	54	A
	3	2	4	7	9	21	45	58	65	A
	4	1	6	11	14	17	38	52	56	A
	4	2	4	8	11	23	45	58	69	A
	5	1	1	3	6	19	47	63	74	A
	5	2	36	43	47	56	66	67	71	A
	9	1	6	9	11	19	35	50	63	A
	9	2	1	3	4	13	28	40	47	A
	10	1	11	12	15	25	48	59	64	A
	10	2	3	4	6	19	51	69	75	A
	13	1	6	8	9	17	33	43	51	A
	13	2	1	2	2	19	52	69	74	A
	14	1	3	3	4	17	49	63	68	A
	14	2	8	11	13	25	48	62	63	A
	16	1		9	15	39	72	91	98	A
	16	2		25	30	45	67	75	94	A
	17	1	14	19	23	36	49	65	71	A
	17	2	6	8	10	23	48	62	70	A
75	1	2	3	6	9	19	37	47	54	A
	1	3	21	26	29	40	49	59	72	A
	1	4	10	15	18	39	52	62	68	A
	2	2	5	9	11	23	49	61	68	A
	2	3	5	8	12	26	52	59	68	A
	2	4	11	14	17	31	58	69	75	A
	2	6	28	36	38	52	65	74	82	A
	3	2	12	15	17	27	43	55	63	A
	3	3	4	9	13	26	48	61	73	A
	3	4	3	6	8	18	39	40	45	A
	4	2	7	8	10	23	55	66	71	A
	4	3	2	4	6	18	40	51	65	A
	4	4	31	33	36	45	67	73	76	A

(continued)

TABLE 25. (continued)

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
	5	2	21	24	26	33	47	50	51	A
	5	3	4	10	13	19	31	48	62	A
	5	4	1	3	4	15	44	55	60	A
	6	2	5	7	9	19	43	51	59	A
	6	3	2	3	5	17	41	57	70	A
	6	4	13	14	15	23	43	54	65	A
	7	2	3	6	8	23	54	69	75	A
	7	3	2	4	6	17	40	55	70	A
	7	4	1	8	12	14	51	72	73	A
	8	2	8	11	11	11	26	38	49	A
	8	3	3	5	7	18	33	45	58	A
	8	4	9	13	17	28	50	57	65	A
98	1	1	1	1	1	30	77	93	100	B
99	1	1	6	11	13	28	32	33	37	B
	2	1	8	17	22	43	71	84	93	B
	3	1	8	13	21	46	62	73	84	B
100	1	1	3	5	6	10	11	11	19	B
	2	1	9	17	32	51	70	81	90	B
101	1	1		1	1	8	29	32	34	B
	2	1		1	1	9	31	39	44	B
	3	1	1	4	5	17	34	38	38	B
	4	1	1	3	6	17	28	33	34	B
	5	1	1	3	4	20	38	42	47	B
	6	1	2	3	5	15	42	53	63	B
	7	1	2	4	5	17	31	36	45	B
	8	1	2	4	4	8	18	30	43	B
	10	1	2	3	6	22	57	76	89	B
102	1	1	8	8	8	10	29	34	35	B
	2	1		3	3	9	20	22	23	B
	3	1	3	7	11	30	53	54	55	B
	4	1	4	6	8	15	38	43	43	B
	5	1	6	15	19	39	64	69	72	B
	7	1	1	1	1	3	7	9	12	B
	8	1	3	5	6	11	16	17	19	B
	10	1	1	3	5	20	58	74	85	B
	11	1	1	9	12	24	38	42	48	B
	12	1	2	2	3	13	29	32	32	B
	12	2				4	10	12	13	B
103	1	1	1	3	5	20	45	51	59	B
	2	1	2	2	5	27	49	52	57	B
	3	1		5	5	12	59	65	67	B
	3	3	13	14	15	25	34	41	59	B
	4	1				21	45	61	69	B
	5	1	1	3	6	15	33	47	63	B
	6	1		62	65	77	93	94	95	B
A RANK DATA AVERAGE			8	11	14	25	48	59	68	
B RANK DATA AVERAGE			4	8	10	22	41	48	54	
A+B RANK DATA AVERAGE			7	10	13	24	46	55	63	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 26. PARTICLE SIZE DISTRIBUTION DATA FOR BAGHOUSE CONTROLLED BOILERS BURNING PULVERIZED ANTHRACITE COAL (WITH PETROLEUM COKE)

DATA SET IDENTIFICATION TEST SITE#	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
11	1	2	68	68	69	72	100	100	100	A
	2	2	55	59	61	67	100	100	100	A
73	1	3	7	13	16	26	48	70	97	A
	1	4		9	12	22	44	64	87	A
	2	4	9	19	24	35	57	75	100	A
	2	5	24	42	49	62	73	87	100	A
	3	4	9	16	19	29	57	79	99	A
	3	5	6	14	16	26	54	76	97	A
	4	4		8	12	21	45	71	104	A
	4	5	2	8	10	10	38	71	97	A
	6	4	6	13	18	30	48	69	89	A
	7	4	10	23	30	50	62	84	97	A
	7	5	7	13	18	33	61	78	89	A
	8	4	8	17	21	33	59	79	99	A
	8	5	12	20	23	36	61	79	98	A
	9	4		5	11	22	50	75	100	A
	9	5				22	58	78	96	A
	10	4		5	5	9	34	60	91	A
	10	5				5	26	50	82	A
74	6	1		12	21	43	57	71	86	A
	7	1	5	8	10	18	19	73	84	A
	7	2	12	13	14	16	30	48	69	A
	8	1		5	5	25	41	64	78	A
	11	1		19	29	37	55	75	86	A
	12	1		14	15	19	52	83	96	A
	15	1					22	49	71	A
	15	2			5	11	26	67	94	A
	18	1				23	47	71	85	A
	18	2						55	55	A
	19	1	5	9	11	21	56	79	88	A
	19	2		3.2	5	9	37	65	83	A
75	1	6		9	12	31	58	66	70	A
	3	6		11	15	31	58	75	89	A
	4	6		5	5	6	10	15	21	A
	5	6	97	97	97	98	98	98	98	A
	6	6	65	65	66	81	91	93	94	A
	7	6	40	41	41	44	49	58	67	A
	7	7	8	11	11	11	26	38	49	A
	8	6	36	41	43	54	66	75	81	A
99	3	2	1	12	20	35	69	78	86	B

(continued)

TABLE 26. (continued)

DATA SET IDENTIFICATION TEST SITE*	 TEST NO.	 TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	 1.00	 1.25	 2.50	 6.00	 10.00	 15.00	DATA RANK
100	3	1					19	46	68	B
101	1	2			41	82	86	88	89	B
	2	2			42	83	87	89	90	B
	3	2			7	25	43	63	78	B
	4	2			12	30	57	80	85	B
	5	2		7	9	16	46	62	68	B
	6	2		3	4	5	7	14	30	B
	11	1		3	4	11	19	41	59	B
	11	2		1	1	13	46	65	71	B
102	1	2				59	61	68	74	B
	2	2					16	33	41	B
	3	2			2	3	5	8	27	B
	4	2			9	15	21	25	35	B
	5	2		1	2	23	30	59	66	B
	6	2		10	14	19	34	60	62	B
	7	2		16	16	19	36	38	62	B
	8	2		6	13	17	30	33	48	B
	9	2		5	7	11	40	55	60	B
	10	2				25	37	40	46	B
	11	2				4	21	27	31	B
103	1	2		26	27	41	66	79	92	B
	3	2		5	10	40	88	98	99	B
	3	4		6	12	41	85	96	96	B
	4	2		18	29	72	97	99	99	B
	5	2		62	65	77	93	94	95	B
	6	2		7	13	41	81	93	94	B
A RANK DATA AVERAGE			23**	22	24	32	52	71	86	
B RANK DATA AVERAGE			1**	12	16	32	49	60	69	
A+B RANK DATA AVERAGE			22**	18	21	32	51	67	79	

*SEE TEXT FOR TEST SITE IDENTIFICATION. MOST SITES HAVE MULTIPLE CYCLONES.

**AVERAGE NOT USED DUE TO INCONSISTENCY IN REPORTING.

TABLE 27. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED STOKERS BURNING ANTHRACITE COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
247	1	1		4	5	7	16	21	40	B
253	1	1		46	47	52	83	97	100	B
254	1	1		19	19	21	26	37	53	B
B RANK DATA AVERAGE				23	24	27	42	52	64	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

the data sets were retained for use in development of size-specific emission factors.

TSN 11 contains data from the first recorded study at Sunbury. The effectiveness of a recently installed Western precipitation fabric filter baghouse was examined as well as the compliance of emissions with Commonwealth of Pennsylvania permit requirements.

Baghouse inlet and outlet samples were each drawn twice using Brink BMS-11 impactors. The first inlet/outlet pair was sampled during continuous operation at 103 percent of design capacity with 100 percent of capacity corresponding to 52 kg/s (410,000 lb/hr) of steam production. The second pair occurred during continuous operation at 105 percent of design capacity. Sampling flowrate isokinetic values for the four samples were all reported as 100 percent. This data is A-quality, but the mixed fuel feed renders the applicability of the data questionable.

Test series numbers 73, 74, and 75 contain data from a study in early 1975 which sought to determine the effectiveness of the baghouse under different operating conditions with new and used filter bags.

Extensive sampling was performed on both baghouse inlet and outlet using an Andersen Mark III impactor with a Univeristy of Washington Mark III impactor used for some outlet samples in TSN 75. Operating loads varied from 90 to 100 percent of design capacity. Impactor sampling flowrate isokinetic values were not consistently reported, but those that were reported fall into an acceptable range (92 to 107 percent). Isokinetic values for EPA Method 5 tests went as high as 113 percent. Despite the omission of some validating data, the reported particle size distribution data is A-quality, but the mixed fuel inhibits the data's useful value.

Test series numbers 98, 99, 100, 101, 102, and 103 all report data from the third study at Sunbury Station. In contrast to the other two studies, the baghouse used for these test series was a novel mobile unit developed for the Environmental Protection Agency; also, no operating parameters and few sampling conditions were reported. For example, sampling flowrate isokinetic values were not reported; but testing was performed during continuous operation, baghouse inlet samples were drawn by Brink BMS II impactors, and outlet samples were drawn by Andersen Mark III impactors.

Due to insufficient documentation, this data is considered B-quality. In addition, the use of mixed fuel and the novel control device detract from the value of the data.

TSN 247

This test series contains sampling data from a 12-GJ/hr (3.3-MW) anthracite-coal-fired stoker-fed boiler with uncontrolled emissions. The test site was one of several sites sampled to determine the fine particle emissions from commercial/institutional combustion sources.

One emission sample using a SASS train with cyclones was obtained on February 22, 1978 while the unit was operated continuously at normal maximum conditions. A sampling flowrate isokinetic value of 95 percent was achieved. Although documentation was complete and conditions were acceptable, the use of a SASS train with cyclones for sampling reduces the resultant data to B-quality.

TSN 253

As with TSN 247, the data in TSN 253 came from a study of fine particulate emissions from commercial/institutional combustion sources. A 9.2-GJ/hr (2.6-MW), anthracite-coal-fired, stoker-fed boiler with no particulate control device was the source of emissions.

On March 27, 1979, anthracite was fed at a rate of 756 kg/hr (1,700 lb/hr) yielding 100 percent of steam design capacity. A single stack sampling was drawn using the normal SASS train with three cyclones. Sampling flowrate isokinetic value was 99 percent. Supporting documentation was recorded. Only the choice of sampling device inhibits the overall quality of this data and subsequently makes it B-quality.

TSN 254

The source specifications for this test series were identical to the source for TSN 253 which was drawn from the same reference report, but is located at a different site. The unit for this test series was a 9.2-GJ/hr, anthracite-coal-fired, stoker-fed commercial/institutional boiler without any emission controls.

While operating continuously at 100 percent of design capacity on March 29, 1979, a single sample was drawn using a SASS train with cyclones. The sampling flowrate isokinetic value was 99 percent. As with all SASS train data, this data is B-quality.

3.3.3 Fuel Oil

Cumulative size-specific particle size distribution data for each emission source and control device for fuel oil combustion are listed in Tables 28 through 35. The tables also include an assigned rating for each data set.

The FPEIS data base managed by the Environmental Protection Agency was extensively used to provide data sets for this study. A discussion of these data sets and those obtained from other reports follows. The FPEIS data sets are listed numerically by their TSN and followed by a discussion of the other relevant tests.

TSN 14

An industrial watertube boiler with no emission control device rated at 23.4-GJ/hr (6.5-MW) thermal output (2.2×10^7 Btu/hr) was the emissions

TABLE 28. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED UTILITY BOILERS BURNING RESIDUAL FUEL OIL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
17	1	1	24	39	46	71	93	98	100	A
	1	2	25	48	57	74	88	94	97	A
	3	1	25	48	57	74	88	94	97	A
	3	2	25	41	48	65	81	90	95	A
23	1	1	1	1	3	8	31	60	80	B
24	1	1	4	5	6	11	29	49	68	B
72	1	1		24	32	51	57	63	71	C
	2	1		45	49	58	60	61	67	C
	3	1		43	44	49	54	60	68	C
	4	1		54	56	62	66	71	77	B
	5	1		40	45	55	60	64	71	C
186	1	1		12	17	30	38	46	57	B
	2	1		13	20	37	55	65	75	B
	3	1		55	56	59	61	65	72	B
	4	1		58	61	70	6	93	98	B
188	1	1		85	86	88	89	90	92	C
	2	1		41	42	47	67	78	87	C
	3	1		71	72	76	80	83	87	B
	4	1		53	54	60	69	75	81	B
	5	1		83	85	87	89	91	92	C
	6	1		49	52	61	71	77	83	C
198	1	1		78	79	82	91	96	99	C
212	1	1				56	58	59	70	C
	1	2	48	49	49	50	52	55	68	C
213	1	1				44	47	50	63	B
	1	2	33	35	36	41	51	60	73	C
214	1	1				41	46	54	68	B
	1	2	37	41	43	46	49	52	67	B
A RANK DATA AVERAGE			25	44	52	71	88	94	97	
B RANK DATA AVERAGE			14	36	39	45	48	64	74	
C RANK DATA AVERAGE			41	52	54	60	67	71	78	
A+B RANK DATA AVERAGE			20	39	43	52	58	71	80	
A+B+C RANK DATA AVERAGE			25	44	48	55	62	71	79	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 29. PARTICLE SIZE DISTRIBUTION DATA FOR ESP-CONTROLLED UTILITY BOILERS BURNING RESIDUAL FUEL OIL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
22	1	1	10	14	17	26	41	55	71	C
192	1	1		41	45	55	63	71	79	C
C RANK DATA AVERAGE			10	28	31	41	52	63	75	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 30. PARTICLE SIZE DISTRIBUTION DATA FOR SCRUBBER-CONTROLLED UTILITY BOILERS BURNING RESIDUAL FUEL OIL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
17	2	1	71	85	90	96	100	100	100	A
	2	2	49	80	90	98	100	100	100	A
	4	1	67	85	91	97	100	100	100	A
	4	2	67	85	91	97	100	100	100	A
A RANK DATA AVERAGE			64	84	91	97	100	100	100	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 31. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED INDUSTRIAL BOILERS BURNING RESIDUAL FUEL OIL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
14	1	1		69	71	76	83	87	91	B
	2	1		15	16	22	29	39	52	B
	3	1		40	41	47	76	91	99	C
	4	1		24	25	31	47	59	70	C
59	1	1	43	47	48	69	96	100	100	B
	1	2	39	41	43	60	82	91	95	B
	2	1	38	41	43	58	82	91	95	B
	3	1	14	17	18	44	76	88	94	B
	4	1	40	43	46	55	65	75	84	B
60	1	1	59	59	61	78	89	94	97	B
	2	1	20	33	43	66	85	92	96	B
61	1	1	14	17	19	24	31	35	48	C
62	1	1	12	20	27	62	92	99	100	B
	2	1	27	39	43	58	94	100	100	B
	3	1	4	8	11	26	49	66	79	B
67	1	1	34	37	39	54	83	92	97	B
	2	1	31	33	34	49	76	87	93	B
B RANK DATA AVERAGE			30	36	39	56	77	86	91	
C RANK DATA AVERAGE			14	27	28	34	51	62	72	
B+C RANK DATA AVERAGE			29	34	37	52	73	82	88	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 32. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE-CYCLONE-CONTROLLED INDUSTRIAL BOILERS BURNING RESIDUAL FUEL OIL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
170	1	1		21	21	22	72	95	100	D
D RANK DATA AVERAGE				21	21	22	72	95	100	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 33. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED INDUSTRIAL BOILERS BURNING DISTILLATE FUEL OIL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
66	1	1	1	1	1	5	26	48	67	C
	2	1	3	14	17	19	33	52	69	C
C RANK DATA AVERAGE			2	8	9	12	30	50	68	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 34. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED COMMERCIAL BOILERS BURNING RESIDUAL FUEL OIL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
205	1	1				40	52	62	74	C
	1	2	17	21	23	27	32	37	56	B
206	1	1				43	64	75	85	C
	1	2	17	17	18	24	33	41	59	B
207	1	1				41	53	63	75	C
	1	2	21	23	24	26	28	32	52	C
	1	4			24	29	64	89	98	A
TR-83-110/EE	5	1	18	20	22	33	59	78	89	A
	6	1	17	19	21	30	54	72	85	A
	7	1	19	20	21	30	53	72	86	A
	8	1	15	16	17	25	45	64	78	A
	9	1	20	21	22	30	51	67	80	A
	10	1	22	24	25	35	58	75	87	A
	11	1	5	6	7	13	34	57	76	A
	12	1	5	6	7	12	33	55	74	A
	13	1	6	7	8	15	35	56	74	A
	14	1	6	7	7	13	32	53	72	A
	15	1	7	8	9	16	38	59	77	A
	16	1	5	6	7	12	32	54	73	A
A RANK DATA AVERAGE			12	13	14	22	44	64	79	
B RANK DATA AVERAGE			17	19	21	26	33	39	58	
C RANK DATA AVERAGE			21	23	24	38	49	58	72	
A+B RANK DATA AVERAGE			13	14	16	23	44	62	78	
A+B+C RANK DATA AVERAGE			13	15	16	26	45	61	76	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 35. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED COMMERCIAL BOILERS BURNING DISTILLATE FUEL OIL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
TR-83-110/EE	1	1	18	18	19	22	29	36	43	A
	3	1	40	42	44	50	61	69	75	A
	4	1	48	50	51	54	58	60	62	A
A RANK DATA AVERAGE			35	37	38	42	49	55	60	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

source for TSN 14. The unit was fired with different fuels to examine the effect of combustion modifications on NO_x emissions. FPEIS report only gives data from residual oil-fired tests during March 1977.

Four test runs, each containing one sample with particle size distribution data, were reported. Particle size data was taken with Acurex Corporation's prototype SASS train with three cyclones. Normal operating conditions prevailed for the first two tests and the remaining two occurred with combustion modifications.

The first test fired fuel containing 0.55 percent by weight sulfur generating steam at 1.81 kg/s (14,290 lb/hr) corresponding to 84.4 percent of design capacity. Although sampling flowrate isokinetic value was 100 percent with all other conditions acceptable, the less reliable sampling methodology makes this data B-quality.

The second test reported in TSN 14 was with 1.17 weight percent sulfur fuel producing 1.85 kg/s (14,600 lb/hr) steam corresponding to 86.0 percent of design capacity. The sampling flowrate isokinetic value was 107 percent. Again, despite acceptable testing conditions, the sampling methodology reduces the data to B-quality.

The third test was performed while 1.18 weight percent sulfur fuel was being burned, producing 1.82 kg/s (14,370 lb/hr) of steam corresponding to 84.8 percent of design capacity. The sampling flowrate isokinetic value of 111 percent falls outside the acceptable range. The use of a SASS train with cyclones outside the acceptable sampling flowrate isokinetic value range makes this data C-quality.

The fourth test in the series is reported to have occurred almost simultaneously with the third test. The weight percent sulfur value of the residual oil was 1.02. Steam output was 1.78 kg/s (14,050 lb/hr) corresponding to 83.1 percent of design capacity. This sample was taken at 115 percent of sampling flowrate isokinetic value. Again, this data being from a SASS sample outside the acceptable sampling flowrate isokinetic value range makes it C-quality.

TSN 17

The data within this report comes from tests on a 558-GJ/hr (155-MW) residual oil-fired utility boiler. The specific unit sampled was Mystic Station no. 6 in Everett, Massachusetts operated by Boston Edison. A liquid scrubber was in use and had been in operation on the unit for the 6 months prior to testing.

Two sets of four samples each were taken. Each set contained two uncontrolled samples taken by Brink impactors plus two scrubber outlet samples taken by Andersen Mark III impactors. All sampling was reported to have been drawn under 100 percent sampling flowrate isokinetic value conditions. The operating rate for the first sampling set was 80.6 percent of design capacity (3.1×10^4 L/hr (8,000 gph) feed rate) and the rate for the second set was 54.8 percent of design (2.1×10^4 L/hr (5,500 gph)).

Although the operating rate was low for the second set of sampling, the conditions and methods used for both sampling sets are of a reliable nature and hence the data from all eight samples is A-quality.

TSN 22

This FPEIS report contains an average of 10 runs sampled from a Boston Edison residual oil-fired boiler. The unit was characterized by an air atomizer system and a single-stage ESP controlling emissions.

The samples are all ESP-controlled and taken during continuous operation with a 248-GJ/hr (69-MW) electrical output. An Andersen impactor was the measurement device and reportedly leaked during sampling. Additionally, sampling was not conducted isokinetically (no sampling flowrate isokinetic value was included, only the particle size preference was towards coarser particles). Given the departure from reliable methodology, this data is considered B-quality.

TSN 23

As with TSN 22, this report is averaged data from nine runs from a Boston Edison residual oil-fired utility boiler. Although this system has an ESP control device, all samples were taken upstream of the ESP without benefit of an emissions control device. A mechanical oil atomizer was used on this unit. Output for testing was 302-GJ/hr (84-MW) under normal operating conditions.

An Andersen impactor was the sampling device. As with TSN 22, leaks occurred during testing and sampling was not conducted isokinetically. These problems reduced the data to B-quality.

TSN 24

This report is the third in a set of testing at a Boston Edison facility. The data in this report came from an average of eight samples on a 288-GJ/hr (80-MW) boiler tangentially firing residual oil using a steam atomizer. Although the facility has a single-stage ESP for emissions control, all emissions samples were taken upstream of the ESP and represent emissions from an uncontrolled source.

The unit operated at 100 percent of design capacity during Andersen impactor sampling. The impactor sampling flowrate was only 68 percent of isokinetic value and occasionally leaked. The poor measurement conditions reduce the data to B-quality.

TSN 59

Sample results from a 84-GJ/hr (23.4-MW) residual oil-fired industrial boiler located in New York are documented in this test series. No emission controls were in place. One fuel sample was reportedly analyzed showing a sulfur content of 1.60 weight percent.

Five samples were drawn during the study using a Brink BMS-11 impactor. Loads ranged from 62.5 to 80.0 percent of design capacity during sampling. Supporting documentations including sampling flowrate isokinetic values, was not contained in this FPEIS report. This lack of validating information reduces these data sets to B-quality.

TSN 60

A 105-GJ/hr (29.3-MW) residual oil-fired industrial boiler was the source for FPEIS Test Series Number 60. No emission control devices were in use.

Baseline conditions prevailed for two particle size distribution samplings with a Brink BMS-11 impactor. Residual oil containing 1.29 weight percent sulfur was fired producing steam at 84 percent of design capacity. Little supporting documentation was recorded in the FPEIS report. Most notably, the sampling flowrate isokinetic value was omitted. Although testing appears to be A-quality, this lack of substantiating data reduces the test results to B-quality for both samples.

TSN 61

This test series reports the results from a single sampling of the emissions from an uncontrolled 74-GJ/hr (20.5-MW) industrial boiler located in Illinois. Residual oil was steam atomized and fired to produce only 41.4 percent of design capacity. The low load renders this data set marginal for use in the development of emission factors. Other process conditions are undocumented.

The single sample was taken by a Brink BMS-11 impactor. Sampling conditions are almost entirely unspecified including no reported sampling flowrate isokinetic value. While this is impactor data, the low process rate and lack of validating data make the size data C-quality.

TSN 62

Test series number 62 reports results from testing on a 158-GJ/hr (43.9-MW) individual boiler located in Minnesota firing steam-atomized residual oil. The emissions were uncontrolled.

Three particle size distribution samples were taken with a Brink BMS-11 impactor. Identical ultimate fuel analyses were given with the sulfur content listed as 2.74 percent by weight. The process rates varied slightly in the range of 46.3 to 48.0 percent of design capacity. Few other process and sampling conditions were included. No sampling flowrate isokinetic value was listed for any of the three samples. The lack of sufficient validating evidence reduces this impactor data to B-quality.

TSN 66

The emissions source in FPEIS test series number 66 was a 158-GJ/hr (43.9-MW) distillate oil-fired industrial boiler located in Ohio. Although an ESP controlled stack emissions, the two reported samplings for TSN 66 were taken at the ESP inlet and, hence, were uncontrolled. Both samples were gathered with a Brink BMS-11 impactor. Process conditions for the first test were not mentioned, except for a process rate of 36.7 percent of design capacity and a fuel sample ultimate analysis. The second test reports a process rate of 40.7 percent of design and is otherwise incomplete. Sampling conditions are also incomplete with reported sampling flowrate isokinetic values being omitted for both tests.

The lack of substantiating data coupled with low operating rates detract from the value of the data and make it C-quality.

TSN 67

This FPEIS report lists particle size distribution results from a 42-GJ/hr (11.7-MW) residual oil-fired industrial boiler located in New York. No control devices were in use.

Two size distribution samples were taken using a Brink BMS-11 impactor. The first sampling was performed with the boiler at 81.3 percent of design capacity while the second was performed with the boiler at 80.0 percent. Both tests reported identical fuel analyses with a 1.91 weight percent sulfur content. No other process information was reported. The only sampling conditions given are temperature of the measurement instrument and sampling time. Sampling flowrate isokinetic values were not stated for either test. The lack of validating evidence reduces the particle size distribution data for both test runs to B-quality.

TSN 72

This FPEIS test series data came from testing a 990-GJ/hr (275-MW) residual oil-fired utility boiler during September and October 1977. The source unit no. 4 at the Encina Powerplant in Carlsbad, California, used no emission control device.

Five separate samples were collected during normal operations and included sootblowing during three of the five tests. Operating conditions were all similar. Fuel feed rates ranged from 20.8 kg/s to 21.2 kg/s (165,000 to 168,000 lb/hr) producing 1073 to 1084-GJ/hr (298 to 301-MW) of power. Fuel sulfur content varied from 0.30 weight percent for tests 1 and 2, to 0.47 weight percent for test 3, and to 0.50 weight percent for tests 4 and 5.

The samples were collected with a SASS train with three cyclones. All the sampling flowrate isokinetic values were above the acceptable limit except for test 4 which took place with a 106 percent isokinetic value. Due to the sampling methodology used plus the high isokinetic values during sampling, the particle size distribution data for test runs 1, 2, 3, and 5 is C-quality. Since test 4 is within acceptable isokinetic value limits, this size data is B-quality.

TSN 170

TSN 170 comes from sampling on a no. 6 fuel oil face-fired industrial boiler during October 1977. The emissions from the unit, boiler no. 4 at the Firestone Tire & Rubber facility in Pottstown, Pennsylvania, were controlled by multiple cyclones followed by a pilot FMC double alkali flue gas desulfurization liquid scrubber system.

Only one sample reports sufficient data for PADRE reduction. Although reported as sampled by an Andersen cascade impactor, the sample was reported in SASS format. The sampling flowrate isokinetic value was only 87 percent and some of the large particulate could possibly be from previously burned coal since the unit has a dual-fuel capability. The size data is graded as D-quality.

TSN 186

Sampling reported in this test series was conducted on unit no. 2, a 360-GJ/hr (100-MW) residual oil-fired utility boiler, located at Encina Powerplant, Carlsbad, California. The emissions were uncontrolled.

The purpose of the testing was to determine chemical composition as a function of particulate size distribution. Two sets of samples were collected. Each set of samples consisted of one sample drawn under normal operating conditions followed shortly by a second sample, drawn under identical conditions except the boiler unit underwent sootblow. Each sampling was performed with a SASS train with cyclones.

The first set of sampling took place September 14, 1977. Residual oil with 0.26 weight percent sulfur was fired at a rate of 7.2 kg/s (57,000 lb/hr). Electrical output was 407-GJ/hr (113-MW). The sampling flowrate isokinetic value of the first sampling (normal conditions) was 102 percent. The sampling flowrate isokinetic value of the sootblow sampling was 98 percent. Although the conditions are all acceptable, the choice of sampling device makes this test data B-quality.

The second set of sampling took place October 25 and 26, 1977. Residual oil with 0.33 weight percent sulfur was fired at a rate of 7.2 kg/s (57,000 lb/hr). Electrical output was 366-GJ/hr (101.8-MW). The sampling flowrate isokinetic value of the first sampling in this set (normal conditions) was 96 percent.

The isokinetic value of the sootblow sampling for this set was 105 percent. While these values are not as optimum as the values in the first set, they are still within acceptance limits. The use of a SASS train with cyclones reduces the second pair of sampling data to B-quality.

TSN 188

Similar to TSN 72 and TSN 186, this series of tests was performed at the Encina Powerplant, Carlsbad, California. Uncontrolled emissions were sampled from unit no. 1, a 396-GJ/hr (110-MW) residual oil-fired utility boiler.

The test purpose was to determine the chemical composition of the particulate emissions as a function of size distribution. This was accomplished by collecting three separate sets of samples using a SASS train with cyclones. Each set contained two individual samples. The first sample drawn under normal operating conditions, and the second sample of the set drawn shortly thereafter under similar conditions except the boiler unit underwent sootblow.

The first set of samples were drawn on September 16, 1977. Residual oil was fed at a rate of 8.0 kg/s (64,000 lb/hr) with the electrical output listed as 378-GJ/hr (105-MW). Sulfur content of the oil was 0.23 weight percent during the sample (normal operation) and 0.28 percent for the second sample (sootblow). The isokinetic values were 84 percent and 89 percent for the first and second samples, respectively. Both values fall outside the acceptable sampling flowrate isokinetic value range. Due to these low values plus the use of SASS trains, this first pair of sample data was ranked as C-quality.

The second set of samples were drawn October 13 and 14, 1977. Oil was fired at a rate of 6.6 kg/s (52,000 lb/hr) with an electrical output of 382-GJ/hr (106-MW). Sulfur content of the fuel was 0.38 percent during "normal operation" test and 0.32 percent during the "sootblow" sample. Both samples were collected at 91 percent of sampling flowrate isokinetic value. Only the choice of sampling device reduces the value of the second set of particle size distribution data, making the data B-quality.

The third, and final pair of samples reported in this FPEIS report were collected November 9 and 10, 1977. Residual oil with sulfur content of 0.32 weight percent was fed at a rate of 6.6 kg/s (52,000 lb/hr) producing an electrical output of approximately 371-GJ/hr (103-MW). The isokinetic value of the "normal operation" sampling was 94 percent. The isokinetic value of the "sootblow" sampling was omitted. The use of a SASS sampling train reduces the first size distribution data to B-quality. The omission of a reported sampling flowrate isokinetic value reduces the sootblow condition data to C-quality.

TSN 192

Test series number 192 was performed on a Combustion Engineering tangential firing residual oil-fired 569-GJ/hr (158-MW) utility boiler unit in Delaware on May 25, 1978. A conventional ESP treated boiler exhaust gases.

The unit was operated normally for more than 5 hours during the sampling process. The fuel feed rate was 9.9 kg/s (79,000 lb/hr) producing steam at

96 percent of design capacity. A SASS train with cyclones was used to determine the size distribution for one sample. No sampling flowrate isokinetic value was given, the flowrate in the stack was calculated from the fuel feed rate, and the sample volume was assumed. The sampling conditions are given only marginally. The results are C-quality.

TSN 198

Test series number 198 was conducted July 13, 1977 on a residual oil-fired 612-GJ/hr (170-MW) utility boiler unit (wall firing position) located in California. The fuel feed rate was 11 kg/s (87,000 lb/hr) producing 100 percent of design capacity under normal operating conditions. No emission control devices are used for the test. Ultimate and trace element chemical analysis were run on a 50-mL fuel sample. One particle size test result was reported in moderate detail. The test was run with a SASS train with cyclones sampling the stack for almost 5 hours, but no sampling flowrate isokinetic value was given. Other basic measurement conditions are not specified. The lack of sufficient background data, but with otherwise good methodology gives this size run C-quality.

TSN 205, 206, and 207

Test series numbers 205, 206, and 207 were all performed on the same 80-hp industrial boiler unit at an undisclosed site in Los Angeles, California. The unit contains a Scotch dry-back research firetube boiler. No emission controls are used. The test objective was to prepare a comprehensive emissions inventory of the source by particle size distribution and chemical composition.

All three test series were conducted while the boiler was in continuous ("as needed") operation. An extensive chemical analysis of a fuel sample is given for each series. Also, each series records one particulate size distribution test by a SASS train with cyclones and one size test by a fabricated three-cyclone sampler used in series with a Method 5 train. The SASS train sampled flue gas 2.1m from a horizontal bend. The location of the fabricated cyclones probe is not given. All runs were taken at less than 70 percent steaming capacity.

The testing for TSN 205 occurred on September 13, 1977. The unit was firing crude oil at a rate of 0.023 kg/s, (183 lb/hr) corresponding to 69 percent of design capacity. The SASS train with cyclones operated at 114 percent of sampling flowrate isokinetic value and is supported by thorough documentation. This data is at best C-quality because of low operating conditions and high isokinetic value. The fabricated cyclone operated at a stated 100 percent of sampling flowrate isokinetic value but has few records with which to substantiate this. This lack of documentation plus the questionable test device necessitates a B-quality rating.

TSN 206 comes from data taken September 15, 1977. Low sulfur no. 6 fuel oil was fired at a rate of 0.023 kg/s (183 lb/hr) corresponding to 70 percent of design capacity. The SASS train was operated at 138 percent of sampling flowrate isokinetic value. Complete data is reported, but the less than ideal sampling results in C-quality data. The fabricated cyclone sampler operated at 91 percent of sampling flowrate isokinetic value, but otherwise insufficient test data and also the nonstandard sampling device lead to a B-quality rating.

TSN 207 is from September 20, 1977 test data taken while the boiler unit fired crude oil at a feedrate of 83.1 kg/hr (183 lb/hr) producing steam at 68.8 percent of design capacity. The ultimate analysis of the fuel sample is identical as for TSN 205, but the elemental analysis differs. The SASS train sampler was operated at 122 percent sampling flowrate isokinetic value. The low load capacity and high isokinetic value make the results C-quality despite thorough data records. The fabricated cyclone sampler had a low sampling flowrate isokinetic value (79 percent) with sketchy records. This data is rated as C-quality.

TSN 207 also had a particle size sample taken with an Andersen Model III impactor. The quality of the test device, acceptable sampling flowrate isokinetic value (95 percent) and adequate records make this impactor data A-quality.

TSN 212, 213, and 214

Test series numbers 212, 213, and 214 were all conducted on the same residual oil-fired, 1728-GJ/hr (480-MW) utility boiler unit in Los Angeles, California.

The unit contains a Babcock & Wilcox supercritical boiler with 32 horizontally opposed gas and oil burners. No emission controls were used.

The test objective was to prepare a comprehensive emissions inventory by particle size distribution and chemical composition.

For test series number 212, testing occurred January 27, 1978 under continuous ("as-load demands") operation at only 49 percent of design capacity. The fuel feedrate was 14.5 kg/s (115,000 lb/hr). Two particle size emission samples were taken simultaneously during one 4-hour test. Emission sampling conditions are well documented but other unit operating parameters are vague. A fuel-oil sample underwent extensive chemical analysis.

One emission sample was taken with a SASS train with cyclones with a 77 percent sampling flowrate isokinetic value. Sampling conditions are well documented as is a chemical analysis of the particulate catch. The second (smaller) emission sample was taken from the same stack location as the first sample with three fabricated cyclones used in series with a Joy train with an 88 percent sampling flowrate isokinetic value. Although TSN 212 contains significant documentation, the low operating load, low isokinetic values, and questionable accuracy of the fabricated sampler reduces data to C-quality.

For TSN 213, testing occurred March 6, 1978 under continuous operation at 95 percent of design capacity. The fuel feedrate was 26.6 kg/s

(211,000 lb/hr). As with TSN 212, the other unit operating parameters are vague, except for an extensive chemical analysis of a fuel sample. Two particle size emissions samples were taken, one by a SASS train with cyclones and the other by three fabricated cyclones used in series with a Method 5 train.

The SASS sample was taken with a 92 percent sampling flowrate isokinetic value with adequately documented sampling conditions. The second sample cites minimal sampling conditions, omitting any reported sampling flowrate isokinetic value.

As the SASS train sample was taken under acceptable conditions with proper records, it merits a grade of B-quality. But since the fabricated cyclone sample used questionable methodology with insufficient documentation, it merits a C-quality grade.

For TSN 214, testing occurred March 8, 1978, under continuous operation at 95 percent of design capacity. The fuel feed rate was 26.4 kg/s (210,000 lb/hr). Again, the other operating parameters are vague, except for an extensive chemical analysis of the fuel. Two particulate size samples were taken, one by a SASS train with cyclones and the other by three fabricated cyclones used in series with a Method 5 train.

The SASS sample was taken with a 100 percent sampling flowrate isokinetic value with adequate documentation. The fabricated cyclone sample was taken with a 101 percent sampling flowrate isokinetic value with marginal documentation.

Again the SASS train sample was taken under acceptable conditions with proper records and merits a B-quality rank. But the fabricated cyclone merits a B-quality rank due to the questionable methodology and marginal data on sampling conditions.

AT Report TR-83-110/EE (Ref. 13)

A comprehensive particulate emissions test program was conducted from April 21 through April 28, 1982 on uncontrolled emissions from a 2.6-GJ/hr (732-kW (2.5 million Btu/hr)) North American Scotch-type watertube boiler located at EPA's Industrial Environmental Research Laboratory (IERL) in Research Triangle Park, North Carolina.

All testing was conducted at the outlet stack of the boiler while firing one of three different fuel oils at 52 l/hr (13.7 gph). The first series of tests was run firing a no. 2 distillate fuel, the second series were run firing a no. 6 residual oil with 1 percent sulfur content, and the third series were conducted burning a no. 6 residual oil with 2.9 percent sulfur content. Particle size distribution samples were obtained by Acurex personnel using an Andersen Mark III cascade impactor. The sampling flowrate isokinetic values for the 15 outlet samples ranged from a low of 98.1 percent to a high of 101.7 percent.

Sampling is well documented and the boiler is representative of small boilers in common usage and renders the reported particle size distribution data as A-quality.

3.3.4 Natural Gas

Natural gas particulate size distribution data was not found for external combustion sources. However, a literature search revealed that 100 percent of the particulate from boilers of industrial size are expected to be less than 1 µm (Ref. 5). Based upon that estimate and until additional particulate data is brought forward, an assumed particulate size distribution for natural gas-fired utility boilers, industrial boilers, plus domestic and commercial boilers is that all particulate is less than 1 µm. A statement to this effect is simply added to Section 1.4, Natural Gas Combustion, of AP-42.

3.3.5 Wood Waste

Cumulative size-specific particle-size distribution data for each emission source and control device for wood waste combustion are listed in Tables 36 through 48. The tables also include an assigned rating for each data set.

3.3.6 Emission Source Discussion

The FPEIS data base managed by the Environmental Protection Agency was extensively used to provide data sets for this study. A discussion of these data sets and those obtained from other reports follows. The FPEIS data sets are listed numerically by their test series number (TSN) and followed by a discussion of the other relevant tests.

TSN 109

The emission source for the data of this FPEIS report was a bark-fired industrial boiler. A knock-out elbow for large particulate followed by a fabric filter baghouse controlled emissions. Flyash was pneumatically transported to an unloading cyclone and the transport air was either returned to the baghouse inlet or vented to the atmosphere.

On March 16, 1976, three test sets of three samples each were extracted using a Sierra 226 impactor. The sampling point for two relevant test sets was located between the knockout elbow and the baghouse. The sampling point for one test set was located in the ash transport air return from the unloading cyclone and is not relevant to emission factor development. The sampling flowrate isokinetic values for all samples were reported as 100 percent. The boiler unit was operating with a continuous steam output of 4.4 kg/s (3.5 x 10^4 lb/hr) for the first set, 5.7 kg/s (4.5 x 10^4 lb/hr) for the second set, and 6.3 kg/s (5.0 x 10^4 lb/hr) for the third set.

Each relevant sampling's methodology and documentation were acceptable, and subsequently, all that data are considered A-quality.

TABLE 36. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED BOILERS BURNING BARK[a]

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
109**	1	1	17	25	27	34	39	42	48	A
	1	2	7	12	13	19	23	27	35	A
	1	3	6	7	7	12	17	20	27	A
	3	1	7	11	12	17	21	23	28	A
	3	2	12	17	19	29	36	40	47	A
	3	3	11	16	18	27	31	34	40	A
80-WFB -2	1	1	10	17	18	20	25	49	69	A
	1	2	8	9	10	17	31	43	53	A
	1	3	10	20	24	32	51	64	74	A
80-WFB -8	1	3	3	4	4	7	10	12	13	B
	1	4	5	8	10	16	24	27	29	B
A RANK DATA AVERAGE			10	15	16	23	30	38	47	
B RANK DATA AVERAGE			4	6	7	12	17	20	21	
A+B RANK DATA AVERAGE			9	13	15	21	28	35	42	

*SEE TEXT FOR TEST SITE IDENTIFICATION.
**AFTER KNOCK-OUT/SETTLING HOPPER.

[a] All spreader stoker boilers.

TABLE 37. PARTICLE SIZE DISTRIBUTION DATA FOR A MULTIPLE-CYCLONE-CONTROLLED BOILERS WITH FLYASH REINJECTION BURNING BARK[a]

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
80-WFB -4	1	1	22	24	26	38	75	92	98	B
	1	2	26	27	28	35	62	80	91	A
	1	3	20	27	29	44	66	78	86	B
80-WFB -5	1	1	1	2	12	36	53	70	91	B
	1	2	8	10	12	30	60	76	86	B
	1	3	10	12	14	28	56	74	86	A
	1	4	17	40	54	61	77	84	88	A
	1	5	18	22	23	47	79	92	98	B
	1	6	13	26	33	40	47	65	87	B
A RANK DATA AVERAGE			18	26	32	41	65	79	88	
B RANK DATA AVERAGE			14	19	23	39	63	79	91	
A+B RANK DATA AVERAGE			15	21	26	40	64	79	90	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

[a] All spreader stoker boilers.

TABLE 38. PARTICLE SIZE DISTRIBUTION DATA FOR SCRUBBER-CONTROLLED BOILERS BURNING BARK

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
80-WFB	1	1	23	30	34	49	63	69	73	A
-4**	1	2	28	31	36	48	78	92	98	A
	1	3	40	47	49	77	89	91	92	A
80-WFB	1	1	5	18	27	65	91	96	98	A
-5**	1	3	5	13	21	66	90	95	96	A
	1	4	5	13	21	63	86	91	93	A
	1	5	5	8	10	17	37	57	74	A
	1	6	13	28	40	56	77	86	92	A
A RANK DATA AVERAGE			14	23	29	56	78	87	92	

*SEE TEXT FOR TEST SITE IDENTIFICATION.
**MULTIPLE CYCLONES UPSTREAM WITH FLYASH REINJECTION.

TABLE 39. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED BOILERS BURNING WOOD/BARK[a]

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
256	1	1		63	66	74	85	90	94	C
259	1	1		70	72	78	86	90	94	C
C RANK DATA AVERAGE				67	69	76	86	90	94	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

[a] All underfeed stoker boilers.

TABLE 40. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED BOILERS BURNING WOOD/BARK[a]

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
260	1	1		52	54	59	67	74	82	C
C RANK DATA AVERAGE				52	54	59	67	74	82	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

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[a] Fluidized bed combustor with heat recovery boiler.

TABLE 41. PARTICLE SIZE DISTRIBUTION DATA FOR UNCONTROLLED BOILERS BURNING SALT-LADEN WOOD/BARK[a]

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
141	1	1	7	7	7	7	7	7	14	B
	1	2	14	14	15	17	18	19	26	B
B RANK DATA AVERAGE			11	11	11	12	13	13	20	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

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[a] All spreader stoker boilers.

TABLE 42. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE CYCLONE-CONTROLLED BOILER WITH FLYASH REINJECTION BURNING WOOD/BARK[a]

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
80-WFB-10	1	1	20	30	37	71	88	92	94	A
	1	2	12	15	18	33	67	86	95	A
	1	3	15	26	34	57	86	95	98	A
A RANK DATA AVERAGE			16	24	30	54	80	91	96	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

[a] Spreader stoker boiler.

TABLE 43. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE CYCLONE-CONTROLLED BOILER WITH FLYASH REINJECTION BURNING SALT-LADEN WOOD/BARK[a]

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
138	1	1	55	63	65	73	82	87	90	B
	1	2	55	69	73	84	91	93	95	B
	1	3	51	62	64	69	81	85	86	B
	2	1	23	32	32	35	65	74	77	B
	2	2	34	43	44	48	61	66	71	B
	2	3	46	60	69	81	83	86	88	B
	2	4	45	57	57	60	61	65	69	B
	3	1	45	56	56	60	72	76	79	B
	4	1	26	36	37	42	57	64	69	A
	4	2	42	50	51	53	64	67	72	A
	5	1	33	38	38	43	56	63	72	A
	6	2	41	43	43	53	78	94	100	A
	6	3	36	37	38	47	50	62	75	A
	7	1	25	27	27	34	52	67	80	A
	8	1	77	78	78	81	90	97	100	A
A RANK DATA AVERAGE			40	44	45	50	64	73	81	
B RANK DATA AVERAGE			44	55	58	64	75	79	82	
A+B RANK DATA AVERAGE			42	50	51	58	70	76	82	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

[a] Spreader stoker boiler.

TABLE 44. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE CYCLONE-CONTROLLED BOILER WITH NO FLYASH REINJECTION BURNING WOOD/BARK[a]

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
NCASI PROVIDED DATA	1	2	5	8	10	17	26	31	35	B
	1	3	2	5	7	16	27	33	35	B
	1	4	3	6	9	18	32	38	40	B
	1	6	3	6	7	13	21	25	28	B
B RANK DATA AVERAGE			3	6	8	16	27	32	35	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

[a] Spreader stoker boiler.

TABLE 45. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE CYCLONE-CONTROLLED BOILER WITH NO FLYASH REINJECTION BURNING SALT-LADEN WOOD/BARK[a]

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
80-WFB-9	1	1	20	22	24	26	31	35	39	A
	1	2	17	21	22	23	37	50	63	A
	1	3	5	12	16	21	33	39	42	A
A RANK DATA AVERAGE			14	18	21	23	34	41	48	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

[a] Dutch oven boiler.

TABLE 46. PARTICLE SIZE DISTRIBUTION DATA FOR SCRUBBER-CONTROLLED BOILERS BURNING WOOD/BARK[a]

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
257	1	1		97	98	99	99	99	99	C
258	1	1		93	94	96	96	96	97	C
C RANK DATA AVERAGE				95	96	98	98	98	98	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

[a] All Dutch oven boilers.

TABLE 47. PARTICLE SIZE DISTRIBUTION DATA FOR BAGHOUSE-CONTROLLED BOILERS BURNING SALT-LADEN WOOD/BARK[a]

DATA SET IDENTIFICATION TEST SITE*	TEST NO.	TEST SMPL	CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS) 0.625	1.00	1.25	2.50	6.00	10.00	15.00	DATA RANK
80-WFB	1	1	49	52	57	61	80	90	96	A
-9	1	2	20	37	41	52	68	76	81	A
	1	3	32	42	45	49	62	72	79	A
A RANK DATA AVERAGE			34	44	48	54	70	79	85	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

[a] Dutch oven boiler.

TABLE 48. PARTICLE SIZE DISTRIBUTION DATA FOR DRY ELECTROSTATIC GRANULAR FILTER-CONTROLLED BOILER BURNING WOOD/BARK[a]

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
80-WFB -10	1	1	36	44	49	50	50	63	78	A
	1	2	34	45	48	48	50	58	59	A
	1	3	89	90	91	92	92	93	94	A
	2	1	56	58	59	59	60	61	62	A
	2	2	45	46	48	50	52	54	55	A
	2	3	52	57	58	61	66	69	72	A
	3	1	71	80	83	85	90	93	94	A
	3	2	39	43	47	57	68	74	78	A
	3	3	40	60	70	86	96	98	99	A
A RANK DATA AVERAGE			51	58	61	65	69	74	77	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

[a] Spreader stoker boiler.

TSN 138

This test series presents stack sample data from a forest products company industrial site which burned salt-laden bark and wood wastes to supply plant power. Three separate spreader stober boilers, each with its own multiple cyclones, were served by a single stack.

Fifteen total particle size samplings were performed under three different sets of operating conditions. All samplings were performed with a MRI Model 1502 impactor.

Seven samplings occurred on July 27 and 28, 1976. Cumulative steam output of the three boilers was approximately 5 kg/s (40,000 lb/hr). Other operating and sampling conditions are sparsely documented. No sampling flowrate isokinetic values were reported.

Four more samplings occurred during the period October 26 through 28, 1976. Cumulative steam output had increased to approximately 5.3 kg/s (42,000 lb/hr). Again, little additional information was given, but sampling flowrate isokinetic values were reported for all but the first of these samplings. The second and third samples reported isokinetic values of 102 percent; the fourth sample reported a value of 99 percent.

From June 7 through 9, 1977, a final four additional size samplings were performed. Operating load was only 4.8 kg/s (38,000 lb/hr) of cumulative steam output. Sampling flowrate isokinetic values were 98 percent for the first two runs and 99 percent for the final two runs.

Despite the voids in conditions data, all tests performed with an impactor under acceptable sampling flowrate isokinetic value conditions have size data considered to be A-quality. Size data for tests without a reported sampling flowrate isokinetic value is reduced to B-quality.

TSN 141

The test series data came from a Washington Department of Ecology study for the St. Regis industrial plant, boiler no. 14, in Tacoma, Washington. A mixed wood-bark fuel was fired. No emission controls were in place at the time of the test so all samples were reported as uncontrolled.

Two particle size distribution runs conducted on March 31, 1976 were included in TSN 141. The boiler's steam production rate was noted as an average 7.1 kg/s (56,000 lb/hr) during the first sampling period and 6.8 kg/s (54,000 lb/hr) during the second sampling period. A Nelson cascade impactor was used with sampling flowrate isokinetic values of 87 and 85 percent achieved for respective samplings.

Given the low sampling flowrate isokinetic values the size data is B-quality.

TSN 256, 257, 258, 259, and 260

These five test series were performed during February and March, 1979 as part of a comprehensive study of fine particulates from industrial combustion sources. The industrial boilers for each of these tests fired a wood/bark mixture using underfeed stokers (TSN 256 and 259), Dutch ovens (TSN 257 and 258), and fluid beds (TSN 260). Each test series contains extensive fuel and catch chemical analyses with a single sampling performed with a SASS train with cyclones.

For TSN 256, the Wellons-Birchfield underfeed stoker boiler was designed for 13-GJ/hr (3.7-MW) output. It was operated at full load during sampling and had a fuel feed rate of 16-GJ/hr (4.4-MW) heat input. The boiler has no particulate control equipment so the single SASS sample was for uncontrolled emissions. The isokinetic value for the SASS sample was not included in the FPEIS listing.

The sample data in TSN 257 came from a 57-GJ/hr (16.8-MW) rated output Puget Sound machinery Dutch oven design-boiler operating at 106 percent of capacity with an equivalent fuel feed rate of 76-GJ/hr (21-MW). The sampling occurred downstream of a liquid scrubber under an unspecified sampling flowrate isokinetic value.

Similarly, the SASS sample in TSN 258 was obtained downstream of a liquid scrubber. There was no mention of a sampling flowrate isokinetic value. The source for this sample was a 97-GJ/hr (28-MW) rated output Erie City Iron Works Dutch oven design-boiler operating at 95 percent of capacity with a corresponding fuel feed rate of 115-GJ/hr (32-MW).

For TSN 259, the Babcock & Wilcox underfeed stoker boiler was rated at 43-GJ/hr (12.6-MW). It operated at 80 percent of capacity for sampling with a fuel feed rate of 51-GJ/hr (14.2-MW). The sample data was for uncontrolled particulate emissions, and the sampling flowrate isokinetic value was not reported.

The sample data in TSN 260 was obtained from a 18.5-GJ/hr (5.4-MW) Wellons, Inc. fluid bed boiler which was operated at only 20 percent of full load rating with a fuel input of 5.4-GJ/hr (1.5-MW). One SASS sample was obtained for uncontrolled boiler emissions. Sampling flowrate isokinetic value was not reported for the SASS sample.

Due to the choice of sampling device and the lack of reported isokinetic values, these data are all considered to be C-quality.

Several tests were identified which had not been entered into FPEIS by mid-1983 but had meaningful particle sizing data. Those tests, for the most part, were EPA-sponsored and are listed as follows.

EMB Report 80-WFB-2 (Ref. 14) and -8 (Ref. 17)

These reports, prepared for the Emission Measurement Branch of the Environmental Protection Agency, reported the emissions from an Owens-Illinois Forest Products Division bark-fired industrial stoker-grate boiler located at Big Island, Virginia. A dedicated multiple cyclone unit without flyash reinjection exhausted into a common duct which lead to a pair of ESP's. A coal-fired boiler also exhausted into that common duct.

On December 12, 14, and 15, 1979 the bark-fired boiler was operated at a greater than 11.4 kg/s (90,000 lb/hr) steaming rate while on September 24 and 25, 1980 the boiler was operated at a steaming rate of approximately 22.2 kg/s (175,000 lb/hr). Samples were taken on those data using an Andersen cascade impactor located upstream of the multiple cyclones for the bark-boiler and downstream of the two ESP's.

The ESP outlet sample data were not used since those streams are mixtures of flue gases from coal and bark combustion. The multiple cyclones inlet data of December 12 through 15, 1979 are well documented and considered A-quality while the data of September 24 and 25, 1980 were taken at 80 to 85 percent of the sampling flowrate isokinetic value and are considered B-quality.

EMB Report 80-WFB-4 (Ref. 15)

The particulate for this report was generated by a bark-fired pneumatic spreader stoker boiler with traveling grate and flyash reinjection. The boiler system is located at the St. Regis Paper Company in Jacksonville, Florida. Multicyclones followed by a venturi wet scrubber were used to control emissions.

For January 29 through 31, 1980, three sets for Andersen cascade impactor samples were taken across the venturi wet scrubber. Steam flows during sampling average 13.9 kg/s (110,000 lb/hr) on the 29th, 18.1 kg/s (143,000 lb/hr) on the 30th, and 17.0 kg/s (134,000 lb/hr) on the 31st.

The sampling methodology and documentation are acceptable, except that scrubber inlet run nos. 1 and 3 exceeded 120 percent of the sampling flowrate isokinetic value. Scrubber inlet run nos. 1 and 3, therefore, are considered B-quality while the remaining runs are A-quality.

EMB Report 80-WFB-5 (Ref. 16)

The emissions source for the data of this report was a St. Joe Paper Company bark-fired spreader stoker with traveling grate boiler with screened flyash reinjection from multiple cyclones and a variable throat venturi wet scrubber system. The boiler, located in Port St. Joe, Florida, was sampled during January 17 through 23, 1980.

Two levels of venturi scrubber pressure conditions were tested, namely a ΔP of 8 in. H_2O and 13.5 in. H_2O, and particle sizings were obtained for three sets of samples across the scrubber at each pressure level using an Andersen cascade impactor. The steam output varied from a low of 142.5-GJ/hr (39.6-MW) to a high of 156.3-GJ/hr (43.4-MW).

Four of the six scrubber inlet samples were taken above 110 percent of the sampling flowrate isokinetic value which caused that data to be B-quality. The remaining inlet and outlet samples were taken between 94.4 and 107.1 percent of the sampling flowrate isokinetic value, with acceptable sampling methodology and documentation and the data are considered A-quality.

EMB Report 80-WFB-9 (Ref. 18)

The data in this report was generated from sampling of Dutch-oven-type boilers located at the Bellingham Mill of Georgia-Pacific Corporation in Bellingham, Washington. The boilers were fired with waste wood, of which roughly 80 percent was salt-laden hog fuel. Captured flyash was not reinjected during the test.

The Bellingham Mill was sampled during November 19 through 22, 1980 with one sampling location being between multiple cyclones and a pulse-jet baghouse while the other sampling location was downstream of the baghouse. Three sets of samples were taken using Andersen cascade impactors.

Although fuel feed rates and steam generation rates were not documented, sampling methodology and its documentation were acceptable and, subsequently, all the resultant data are considered A-quality.

EMB Report 80-WFB-10 (Ref. 19)

The data in this report was also incorporated into FPEIS as TSN 283. The Weyerhaeuser Company power boiler no. 11 with a traveling-grate spreader stoker-firing system at Longview, Washington is rated at producing 108-GJ/hr (30-MW) of power. Steam production is rated at 53.2 kg/s (420,000 lb/hr) at 8.6 MPa (1,250 psig) when using 55 percent moisture hog fuel and 72.8 kg/s (575,000 lb/hr) on dry hog fuel, oil, or gas.

Emissions are controlled with a two-stage multiple cyclone system (with a form of flyash reinjection from the first stage) and a three-module Electroscrubber® (a dry electrostatic granular filter device). Two sets of three Electroscrubber inlet and outlet Anderson cascade impactor samples (one inlet and outlet pair per module) were taken during December 9 through 11, 1980. Steam was generated at a rate of 51 kg/s (400,000 lb/hr) on December 9 and 10 but was reduced to 44 kg/s (347,000 lb/hr) on December 11.

Sampling flowrate isokinetic values all appear acceptable, although three values were erroneously omitted from the report. Based on the acceptable sampling methodology and documentation with the slight reservation noted above, the data are considered A-quality.

NCASI (Ref. 20)

The National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI) provided Acurex with particle sizing information which had been provided by a member company for particle size distribution on a bark-fired boiler at the outlet of a single stage of 9-in. multiple cyclones (and inlet to a wet scrubber device). Flyash was not reinjected into the boiler. Unfortunately, NCASI had limited information on the boiler operating conditions but did indicate that the bark and natural gas combination spreader stoker boiler had a rated capacity of 57 kg/s (450,000 lb/hr). Sampling conditions were not reported; however, a University of Washington Cascade Impactor (Mark V low flow with 11 stages) was used with a British Coal Utilization Research Association precyclone and a final filter to separate the particles into 13 fractions according to aerodynamic size. Without more detailed information, especially concerning particle collection conditions and sampling data, this data is only B-quality.

3.3.7 Lignite Coal

Cumulative size-specific particle size distribution data for each emission source and control device for lignite coal combustion are listed in Tables 49 through 51. The tables also include an assigned rating for each data set.

The FPEIS data base managed by the Environmental Protection Agency was extensively used to provide data sets for this study. A discussion of these data sets and those obtained from other reports follows. The FPEIS data sets are listed numerically by their TSN and followed by a discussion of the other relevant tests.

TSN 166

TSN 166 reported data from a 72-GJ/hr (20-MW), pulverized-lignite-coal-fired utility boiler with a conventional multiple cyclones for emissions control. This testing was part of a program to assess the emissions of stationary combustion sources.

One particle size sampling was performed on September 21, 1977 with the boiler operating on a continuous basis at 100 percent of design capacity. The sampling device was a SASS train with cyclones. No mention was made of the sampling flowrate isokinetic value, but other sampling conditions are documented. Chemical analyses were performed on both the lignite fuel and the SASS train catch. This data is C-quality due to the use of a SASS train and insufficient validating data.

TSN 167

This test source could have been the same as for TSN 166 since the source was a 72-GJ/hr (20-MW), pulverized-lignite-coal-fired utility boiler with a mechanical collector for emissions control. As with TSN 166, this

TABLE 49. PARTICLE SIZE DISTRIBUTION DATA FOR AN UNCONTROLLED BOILERS BURNING PULVERIZED LIGNITE COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	RANK
ERC #	WB	-I	4	7	8	11	29	34	47	C
7246	EB	-I	2	5	6	9	22	35	54	C
C RANK DATA AVERAGE			3	6	7	10	26	35	51	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

TABLE 50. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE-CYCLONE-CONTROLLED BOILERS BURNING PULVERIZED LIGNITE COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	RANK
166	1	2	**	2	3	8	27	43	61	C
167	1	2	***	1	3	8	32	49	66	C
ERC #	WB	-O	14	26	30	50	92	94	95	C
7246	EB	-O	16	26	28	42	77	81	85	C
C RANK DATA AVERAGE			8	14	16	27	57	67	77	

*SEE TEXT FOR TEST SITE IDENTIFICATION.
**NOT MORE THAN 2 PERCENT.
***NOT MORE THAN 1 PERCENT.

TABLE 51. PARTICLE SIZE DISTRIBUTION DATA FOR MULTIPLE-CYCLONE-CONTROLLED SPREADER STOKERS BURNING LIGNITE COAL

DATA SET IDENTIFICATION			CUMULATIVE MASS PERCENT LESS THAN STATED SIZE (MICRONS)							DATA RANK
TEST SITE*	TEST NO.	TEST SMPL	0.625	1.00	1.25	2.50	6.00	10.00	15.00	
168	1	2		22	23	26	31	41	55	C
C RANK DATA AVERAGE				22	23	26	31	41	55	

*SEE TEXT FOR TEST SITE IDENTIFICATION.

testing was part of an emissions assessment of stationary combustion sources.

A single particulate size sampling was performed on September 22, 1977 downstream of multiple cyclones. A SASS train with cyclones drew the sample while the boiler operated continuously at 100 percent of design capacity. Sampling conditions were partially recorded, but no sampling flowrate isokinetic value was included. As with TSN 166, this data is C-quality.

TSN 168

This data came from tests performed on a 29-GJ/hr (8-MW), lignite coal-fired utility boiler. By cross-matching test results with the data reference report, this unit was determined to be fed by a spreader stoker. Multiple cyclones were the only emissions control device in use.

A sampling test was run on September 27, 1977 during continuous operation of the boiler at 94 percent of design capacity using a SASS train with cyclones. Sampling conditions were partially reported without any mention of a sampling flowrate isokinetic value. The sampling method and insufficient conditions data result in the size data being C-quality.

ERC No. 7246 (Ref. 21)

The North Dakota State Department of Health provided data from a particulate and gaseous emission inventory performed by Environmental Research Corporation on June 19 through 21, 1972, on the 648-GJ/hr (180-MW) United Power Association's Powerplant IV located in Stanton, North Dakota. The pulverized-lignite-fired boiler had only multiple cyclones with a nominal 62 percent collection efficiency.

The portion of the report sent to Acurex does not adequately describe the sampling methodology and data reduction, but it does describe the approximate 10-stage cascade impactor cut points and mentions that all samples were taken isokinetically. Size distributions for uncontrolled plus multiple-cyclone-controlled emissions were read directly from the figures supplied with the report. Due to the lack of clarifying information, the data sets can only be considered C-quality.

3.4 PARTICULATE EMISSION FACTORS

The development of cumulative size-specific emission factors by weight requires the application of particle size distributions by weight percent to particulate emission factors. Impactors used to collect particle size distribution samples normally are not traversed during sampling and a portion of the particulate is collected on internal surfaces other than impactor plates. SASS trains are also not traversed during sampling. Hence, EPA Method 5 tests provide a more accurate total loading value. In addition, substantially more total loading samples using EPA Method 5 have been taken and should yield a more representative particulate emission factor. External combustion source particulate emission factors in the current edition of

AP-42 are listed in Tables 52 through 56 along with estimated emission factors for controlled sources obtained by applying average collection efficiencies of various particulate control devices (Ref. 5) to the uncontrolled AP-42 particulate emissions factors. This comprehensive cumulative size-specific emission factor development is not used for natural gas combustion (see Section 3.3.4).

3.5 RECOMMENDED CUMULATIVE SIZE-SPECIFIC EMISSION FACTORS

After ranking, grouping, and calculating various averages for the size distribution data, the size distribution by weight percent was combined with a total mass particulate emission factor to form a size-specific emission factor.

The size distributions by weight percent for most source categories were developed from two or more test series. Although A-quality ranked data was preferred, it was almost always necessary to include lower quality data in the calculation of an average size distribution. When test series were combined, the respective particle size distributions were averaged, weighting the data in direct proportion to the number of runs comprising the individual test series average.

The reliability of this size-specific emission factor is indicated by an emission factor rating. The ratings are subjective quality evaluations rather than statistical confidence intervals and range from A (excellent) to E (poor) as follows:

A -- Excellent. Developed only from A-rated particulate emission factors plus A-rated size-specific test data taken from many randomly chosen facilities in the industry population. The source category is specific enough to minimize variability within the source category population.

B -- Above average. Developed only from A-rated particulate emission factors plus A-rated size-specific test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As in the A rating, the source category is specific enough to minimize variability within the source category population.

C -- Average. Developed only from A- and B-rated particulate emission factors plus A- and B-rated size-specific test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

D -- Below average. The emission factor was developed only from A- and B-rated particulate emission factors plus A- and B-rated size-specific test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the

TABLE 52. PARTICULATE EMISSION FACTORS FOR BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

Firing configuration	Emission controls	AP-42 Particulate emission factor (Ref. 1) (kg/Mg)	(Rating)	Average collection efficiency (Ref. 5) (percent by wt)	Particulate emission factors (kg/Mg of coal, as fired)
Pulverized coal fired					
Dry bottom	None	5A[a]	A		5A[a]
	Multiple cyclones	--	--	80	1A
	Scrubber	--	--	94	0.3A
	ESP	--	--	99.2	0.04A
	Baghouse	--	--	99.8	0.01A
Wet bottom	None	3.5A	D	--	3.5A
	Multiple cyclones	--	--	80	0.7A
	ESP	--	--	99.2	0.028A
Cyclone furnace	None	1A	D	--	1A
	Scrubber	--	--	94	0.06A
	ESP	--	--	99.2	0.008A
Spreader stoker	None	30	B	--	30
	Multiple cyclones[b]	8.5[d]	B	--	8.5
	Multiple cyclones[c]	6.0[d]	A	--	6.0
	ESP	--	--	99.2	0.24
	Baghouse	--	--	99.8	0.06
Overfeed stoker	None	8	B	--	8.0
	Multiple cyclones	4.5[d]	B	--	4.5
Underfeed stoker	None[e]	7.5	B	--	7.5
Hand-fired units	None	7.5	D	--	7.5

[a] A is as-fired ash percent by weight.

[b] With flyash reinjection.

[c] Without flyash reinjection.

[d] Since these factors were already listed as controlled particulate emission factors in AP-42, no corresponding average collection efficiency was required to allow calculation of controlled particulate emission factors from uncontrolled emission factors.

[e] Except flyash settling in the breaching downstream of the boiler.

TABLE 53. PARTICULATE EMISSION FACTORS FOR ANTHRACITE COAL COMBUSTION

Firing configuration	Emission controls	AP-42 particulate emission factor (Ref. 1) (kg/Mg)	(Rating)	Average collection efficiency (Ref. 5) (percent by wt)	Particulate emission factors (kg/Mg of coal, as fired)
Pulverized coal fired	None	5A[a]	B	--	5A[a]
	Multiple cyclones	--	--	80	1A
	Baghouse	--	--	99.8	0.01A
Traveling-grate stoker	None	4.6	B	--	4.6
Hand-fed units	None	5.0	B	--	5.0

[a] A is as-fired ash percent by weight.

TABLE 54. PARTICULATE EMISSION FACTORS FOR FUEL OIL COMBUSTION

Firing configuration	Emission controls	AP-42 particulate emission factor[a] (Ref. 1) (kg/Mg)	(Rating)	Average collection efficiency (Ref. 5) (percent by wt)	Particulate emission factors[a] ($kg/10^3$ l)
Utility boilers					
Residual oil	None	A	A	--	A
	ESP	--	--	99.2	0.008A
	Scrubber	--	--	94	0.06A
Industrial boilers					
Residual oil	None	A	A	--	A
	Multiple cyclones	--	--	80	0.2A
Distillate oil	None	0.24	A	--	0.24
Commercial boilers					
Residual oil	None	A	A	--	A
Distillate oil	None	0.24	A	--	0.24
Residential furnaces					
Distillate oil	None	0.3	A	--	0.3

[a] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:

For grade 6 oil: A = 1.25 (S) + 0.38 where S is the weight percent of sulfur in the oil
For grade 5 oil: A = 1.25
For grade 4 oil: A = 0.88

TABLE 55. PARTICULATE EMISSION FACTORS FOR WOOD WASTE COMBUSTION IN BOILERS[f]

Firing configuration	Emission controls	AP-42 particulate emission factor (Ref. 1) (kg/Mg)	(Rating)	Average collection efficiency (Ref. 5) (percent by wt)	Particulate emission factors (kg/Mg of fuel[e])
Bark fired	None	24	B	--	24
	Multiple cyclones[a]	7[d]	B	--	7
	Multiple cyclones[b]	4.5[d]	B	--	4.5
	Scrubber	--	--	94	1.44
Wood-bark fired	None	3.6	C	--	3.6
	Multiple cyclones[a]	3[d]	C	--	3
	Multiple cyclones[b]	2.7[d]	C	--	2.7
	Scrubber	--	--	94	0.22
	Dry electrostatic granular filter	--	--	--	0.16[c]
Wood fired	None	4.4	C	--	4.4

[a] With flyash reinjection.
[b] Without flyash reinjection.
[c] Emission factor calculated using Ref. 3-14.
[d] Since these factors were alreay listed as controlled particulate emission factors in AP-42, no corresponding average collection efficiency was required to allow calculation of controlled particulate emission factors from uncontrolled emission factors.
[e] Based on moisture content of 50 percent for bark, 33 percent for wood/bark, and as-fired for wood.
[f] Particulate emission factors not available for salt-laden wood wastes as well as fluidized bed combustors.

TABLE 56. PARTICULATE EMISSION FACTORS FOR LIGNITE COAL COMBUSTION

Firing configuration	Emission controls	AP-42 particulate emission factor (Ref. 1) (kg/Mg)	(Rating)	Average collection efficiency (Ref. 5) (percent by wt)	Particulate emission factors (kg/Mg of coal, as fired)
Pulverized coal fired					
Dry bottom	None	3.1A[a]	A	--	3.1A
	Multiple cyclones	--	--	80	0.62A
Cyclone furnace	None	3.3A	C	--	3.3A
Spreader stoker	None	3.4A	B	--	3.4A
	Multiple cyclones	--	--	80	0.68A
Other stokers	None	1.5A	B	--	1.5A

[a] A is as-fired ash percent by weight.

industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

E -- Poor. The emission factor was developed from a C-, D-, or E-rated particulate emission factor and/or C- and D-rated size-specific test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always footnoted.

3.5.1 Bituminous Coal

A summary of the data incorporated into each source and control device category for cumulative size specific emission factor development and its assigned rating follows.

Dry-Bottom Pulverized Coal-Fired Systems

The cumulative size-specific emission factor (CSSEF) for uncontrolled emissions from a pulverized-coal-fired, dry-bottom system was developed from averaging more than 100 individual size distribution data sets obtained from nine sites combined with an A-rated particulate emission factor. Due to the limited A-quality data, B-quality data were included in the average. According to the rating criteria, the CSSEF rating can be as high as a C which is appropriate due to the data quantity.

The CSSEF for multiple cyclone controlled emissions was based on limited B-quality ranked size distribution data from one site combined with an estimated particulate emission factor. The resultant CSSEF rating is E-quality.

The CSSEF for wet scrubber controlled emissions was based on A-quality size distribution data from developmental scrubbers and B-quality data from one of the scrubbers which had been further refined plus data from FGD scrubbers installed on two boilers in the Kentucky area. Those data were combined with an estimated particulate emission factor. The CSSEF rating is considered D-quality since size distribution data was included for too few sources.

The size distribution for ESP-controlled emissions was calculated based on more than 100 total A- and B-quality data sets from several sites. B-quality ranked data was included since there was only seven A-ranked data sets. The ESP size distribution data varied substantially. The average size distribution by weight percent was combined with an estimated particulate emission factor to form a CSSEF which is rated as D-quality.

The CSSEF for baghouse controlled emissions was determined using only two B-quality data sets from one facility combined with an estimated particulate emission factor. Based on the limited data and the use of a estimated particulate emission factor, the CSSEF can only be rated as E-quality.

Wet-Bottom, Pulverized-Coal-Fired Systems

The CSSEF for uncontrolled emissions from a pulverized-coal-fired wet-bottom system was calculated based on three size distribution B-quality data sets taken at the same facility combined with a D-rated particulate emission factor. Based on limited sampling and a low particulate emission factor rating, the assigned CSSEF ranking is E.

The CSSEF for multiple-cyclone-controlled emissions is based on a single particle-sizing data set with a C-ranking and is combined with an estimated particulate emission factor which results in an E-rated CSSEF.

The CSSEF for ESP-controlled emissions is based on single sets of C-ranked size data from five sites and is combined with an estimated particulate emission factor (based on a D-ranked factor). The use of low quality data results in a CSSEF with an E rating.

Coal-Fired Cyclone Furnace Systems

The CSSEF for uncontrolled emissions from a coal-fired cyclone furnace was based on one set of size distribution data with a D-ranking combined with a particulate emission factor with a D-ranking and resulted in an E-rated CSSEF.

The CSSEF for wet scrubber controlled emissions from a coal-fired cyclone furnace was based on one set of data with an A-ranking combined with an estimated particulate emission factor. The CSSEF qualifies for an E-rating due to the low quality particulate emission factor ranking.

The CSSEF for ESP-controlled emissions was based on single sets of size distribution data from each of five separate tests combined with an estimated particulate emission factor. Since B- and C-ranked data was combined with an estimated particulate emission factor (based on a D-rated factor), the CSSEF has an E-rating.

Stoker Units

The CSSEF for uncontrolled emissions from spreader stoker boilers is based on more than 40 A-plus B-ranked size distribution samples from six different facilities combined with a particulate emission factor with a B-ranking. B-ranked size distribution data sets were included in determining the average, since only 11 A-ranked data sets were available. The CSSEF has a C-rating.

The CSSEF for emissions from a multiple cyclone control device located downstream from a spreader stoker and employing flyash reinjection was determined using only one set of C-ranked size distribution data combined with a B-rated particulate emission factor. This provides a CSSEF with an E-rating.

The CSSEF for emissions from a multiple-cyclone-controlled spreader stoker was determined using nine A-quality ranked size distribution data sets from two sites combined with an A-rated particulate emission factor. Based on the limited number of facilities represented, the CSSEF rating is C.

The CSSEF for ESP-controlled emissions from a spreader stoker was determined using only one C-quality ranked size distribution data set combined with an estimated particulate emission factor. The resulting CSSEF rating is E.

The CSSEF for baghouse controlled emissions from a spreader stoker was determined using 37 A-quality size distribution data sets from one site plus 22 B-quality data sets from another site combined with an estimated particulate emission factor. All the size distribution data was gathered in 1974. Based on the limited number of sites sampled for size distribution, the age of the size distribution samples, and the estimated particulate emission factor, the CSSEF is C-rated.

The CSSEF for uncontrolled emissions from an overfeed stoker was determined using only one A-quality and two B-quality ranked size distribution data sets combined with a B-rated particulate emission factor. Due to the limited data, the CSSEF rating is D.

The CSSEF for multiple-cyclone-controlled emissions from an overfeed stoker was determined using only three B-ranked size distribution data sets combined with an estimated particulate emission factor. The CSSEF has an E-quality rating.

The CSSEF for uncontrolled emission from an underfeed stoker was determined using one set of B-ranked size distribution data from each of six sites combined with a B-rated particulate emission factor. The CSSEF is assessed a C-rating.

Due to the nonavailability of data for all firing configurations, size distribution estimates need to be made. The estimates are suggested as follows:

Firing configuration	Suggested approximation
Hand-fired units	Use size distribution for underfeed stoker

Valid size distribution data, when obtained, negates the requirement to use these approximations.

The cumulative size distributions and particulate emission factors used in the development of cumulative size-specific emission factors for bituminous and subbituminous coal combustion are shown in Table 57.

TABLE 57. CUMULATIVE SIZE DISTRIBUTIONS AND PARTICULATE EMISSION FACTORS USED IN THE DEVELOPMENT OF CUMULATIVE SIZE-SPECIFIC EMISSION FACTORS FOR BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

		Cumulative mass percent less than stated size							Size distribution data sets			
Firing configuration	Controls	0.625 µm	1 µm	1.25 µm	2.5 µm	6 µm	10 µm	15 µm	Number reviewed	Number used in average	Particulate emission factor (kg/Mg of coal, as fired)	Cumulative size-specific emission factor rating
Pulverized coal fired												
Dry bottom	None	1	2	2	6	17	23	32	126	116	5A[a]	C
	Multiple cyclones	1	1	1	3	14	29	54	4	3	1A	E
	Scrubber	20	31	35	51	62	71	81	62	61	0.3A	D
	ESP	12	14	17	29	50	67	79	127	118	0.04A	D
	Baghouse	14	25	31	53	77	92	97	2	2	0.01A	E
Wet bottom	None	2	4	6	21	33	37	40	3	3	3.5A	E
	Multiple cyclones	--	19	31	61	84	93	99	1	1	0.7A	E
	ESP	--	8	17	40	63	75	83	5	5	0.028A	E
Cyclone furnace	None	0	0	0	0	8	13	33	1	1	1A	E
	Scrubber	--	82	85	92	93	94	95	1	1	0.06A	E
	ESP	--	17	22	36	56	68	80	5	5	0.008A	E
Spreader stoker	None	4	4	5	7	14	20	28	43	42	30	C
After multiple cyclones with flyash reinjection from multiple cyclones	Multiple cyclones	1	2	2	8	51	73	86	1	1	8.5	E
No flyash reinjection from multiple cyclones	Multiple cyclones	9	14	16	27	52	65	74	11	9	6.0	C
	ESP controlled	--	41	46	61	82	90	97	1	1	0.24	E
	Baghouse controlled	7	15	18	26	46	60	72	59	59	0.06	C
Overfeed stoker	None	--	12	13	14	24	37	49	3	3	8	D
	Multiple cyclones	16	39	39	43	49	55	60	3	3	4.5	E
Underfeed stoker	None	18	21	22	25	32	41	50	6	6	7.5	C
Hand-fired units	None	Use size distribution for underfeed stoker.							0	0	7.5	--

[a] A is ash content on an as-fired weight percent basis.

The CSSEF for multiple-cyclone-controlled emissions from an underfeed stoker was originally calculated using only one B-ranked size distribution data set from each of two sites combined with a C-rated particulate emission factor. Due to the limited size distribution data and low emission factor rating, a CSSEF rating of D would have been warranted. However, a significant discrepancy was discovered which resulted in a decision to not include the CSSEF in the AP-42 section. As calculated, this CSSEF resulted in higher emission rates for 15 µm size and smaller particles than would occur with no control devices! Obviously, more size distribution data and total particulate mass emission rate data is required.

3.5.2 Anthracite Coal

A summary of the data incorporated into each source and control device category for cumulative size-specific emission factor development and its assigned rating follows.

Pulverized-Coal-Fired Systems

The CSSEF for multiple cyclone emissions from a pulverized-coal-fired system was developed from the average of 101 A-quality plus B-quality size distribution data sets obtained from one utility site combined with a B-rated particulate emission factor. While these size data sets were taken in a generally acceptable manner, the fuel mixture of anthracite slit, anthracite no. 5 buckwheat, and petroleum coke may make the particulate emissions loading and distribution not representative. The CSSEF is rated D-quality.

The CSSEF for baghouse emissions from a pulverized-coal-fired system was developed from the average of 66 A-quality plus B-quality size distribution data sets obtained from one utility site (but testing new and used fabric filters in its stationary baghouse as well as testing a mobile EPA baghouse) combined with an estimated particulate emission factor. As previously discussed, the fuel was actually composed of anthracite slit, anthracite no. 5 buckwheat, and petroleum coke. The particulate emissions loading and distribution may not be representative for anthracite coal firing. Since the testing was conducted at only one site, and uses an estimated particulate emission factor, the resulting CSSEF is rated as D-quality.

Stoker Units

The CSSEF for uncontrolled emissions from a stoker unit was based on single-B-ranked size distribution data sets from each of three sites combined with a B-rated particulate emission factor. There is a significant variation in the limited size distribution data, so the average data rating is only considered D-quality.

Due to the nonavailability of data for all boiler types, size distribution estimates need to be made. The estimates are suggested as follows:

Boiler type	Suggested approximation
Pulverized coal fired -- no controls	Use size distribution from bituminous coal combustion
Hand-fed units	Use size distribution for traveling-grate stoker

Valid size distribution data, when obtained, negates the requirement to use these approximations.

The cumulative size distributions and particulate emission factors used in the development of cumulative size-specific emission factors for anthracite coal combustion are shown in Table 58.

3.5.3 Fuel Oil

A summary of the data incorporated into each source and control device category for cumulative size-specific emission factor development and its assigned rating follows.

Utility Systems

The CSSEF for uncontrolled emissions from a utility residual oil-fired system was based on a total of 16 A-quality plus B-quality size distribution data sets from eight different sites combined with an A-rated particulate emission factor. Although A-quality size distribution data sets are limited to one site, a sufficient number of B-quality data sets from seven other sites enables the CSSEF to be rated as C-quality.

The CSSEF for electrostatic precipitator controlled emissions from a utility residual oil-fired system was based on only one set of C-ranked size distribution data from each of two facilities combined with an estimated particulate emission factor. Using limited C-ranked data results in an E-quality rating for the average.

The CSSEF for wet scrubber controlled emissions from a utility residual oil-fired system was based on only four sets of size distribution data from one facility combined with an estimated particulate emission factor. Although the size data has an A-quality ranking, the sampling is too limited to provide a utility average and is rated as D-quality.

Industrial Systems

The CSSEF for uncontrolled emissions from an industrial residual oil-fired system was calculated using 14 B-quality size distribution sets from six industrial facilities combined with an A-rated particulate emission factor. With the inclusion of only B-ranked size distribution data, the CSSEF is rated as D-quality.

TABLE 58. CUMULATIVE SIZE DISTRIBUTION AND PARTICULATE EMISSION FACTORS USED IN THE DEVELOPMENT OF SIZE-SPECIFIC EMISSION FACTORS FOR ANTHRACITE COAL COMBUSTION

Firing configuration	Controls	Cumulative mass percent less than stated size							Size distribution data sets		Particulate emission factor (kg/Mg of coal, as fired)	Cumulative size-specific emission factor rating
		0.625 µm	1 µm	1.25 µm	2.5 µm	6 µm	10 µm	15 µm	Number reviewed	Number used in average		
Pulverized coal fired	None		Use size distribution from Table 53						0	0	5A[a]	--
	Multiple cyclones	7	10	13	24	46	55	63	101	101	1A	D
	Baghouse	--	18	21	32	51	67	79	66	66	0.01A	D
Traveling-grate stoker	None	--	23	24	27	42	52	64	3	3	4.6	D
Hand-fed units	None		Use size distribution for traveling-grate stoker						0	0	5.0	--

[a] A is as-fired ash percent by weight.

The size distribution for multiple-cyclone-controlled emissions from an industrial residual oil-fired system was based on only one D-ranked size distribution data set combined with an estimated particulate emission factor. Based on the lack of better quality size distribution data, the CSSEF rating is E.

The CSSEF for uncontrolled emissions from an industrial distillate oil-fired system was determined using only two C-quality size distribution data sets from one test site combined with an A-rated particulate emission factor. Using only C-quality size distribution data results in an E-rated CSSEF.

Commercial Systems

The CSSEF for uncontrolled emissions from a commercial residual-oil-fired system was based on a total of 15 A-quality plus B-quality size distribution data sets from four test sites combined with an A-rated particulate emission factor. This sampling is too limited to provide a commercial average and is rated as only D-quality.

The CSSEF for uncontrolled emissions from a commercial distillate-oil-fired system was calculated using only three A-quality size distribution data sets from one test site combined with an A-rated particulate emission factor. Due to the limited number of A-quality size distribution data sets and sites, the resulting CSSEF is only rated as D-quality.

Due to the nonavailability of data for all boiler types, size distribution estimates need to be made. The estimates are suggested as follows:

Boiler type	Suggested approximation
Residential furnaces	
Distillate oil -- no controls	Use size distribution for commercial boilers

Valid size distribution data, when obtained, negates the requirement to use these approximations.

The cumulative size distributions and particulate emission factors used in the development of cumulative size specific emission factors for fuel oil combustion are shown in Table 59.

3.5.4 Wood Waste

A summary of the data incorporated into each source and control device category for cumulative size-specific emission factor development and its assigned rating follows.

TABLE 59. CUMULATIVE SIZE DISTRIBUTION AND PARTICULATE EMISSION FACTORS USED IN THE DEVELOPMENT OF CUMULATIVE SIZE-SPECIFIC EMISSION FACTORS FOR FUEL OIL COMBUSTION

		Cumulative mass percent less than stated size							Size distribution data sets			
Source category	Controls	0.625 μm	1 μm	1.25 μm	2.5 μm	6 μm	10 μm	15 μm	Number reviewed	Number used in average	Particulate emission factor[a] (kg/10³ l)	Cumulative size-specific emission factor rating
Utility boilers												
Residual oil	None	20	39	43	52	58	71	80	28	16	9A	C
	ESP	10	28	31	41	52	63	75	2	2	0.008A	E
	Scrubber	64	84	91	97	100	100	100	4	4	0.06A	D
Industrial boilers												
Residual oil	None	30	36	39	56	77	86	91	17	14	A	D
	Multiple cyclones	--	21	21	22	72	95	100	1	1	0.2A	E
Distillate oil	None	2	8	9	12	30	50	68	2	2	0.24	E
Commercial boilers												
Residual oil	None	13	14	16	23	44	62	78	19	15	A	D
Distillate oil	None	35	37	38	42	49	55	60	3	3	0.24	D
Residential furnaces												
Distillate oil	None	Use size distribution for commercial boilers							0	0	0.3	--

[a] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:

For grade 6 oil: A = 1.25 (S) + 0.38 where S is the weight percent of sulfur in the oil

For grade 5 oil: A = 1.25

For grade 4 oil: A = 0.88

Bark-Fired Systems

The CSSEF for uncontrolled emissions from a bark-fired spreader stoker boiler system was developed by averaging 11 size distribution data sets from three industrial sites combined with a B-rated particulate emission factor. Bark-firing is extensively used in the forest-products and other industries and requires more than three sites for a representative sample so the CSSEF only warrants a D-rating.

The CSSEF for multiple-cyclone-controlled emissions with flyash reinjection was calculated from nine size distribution data sets from two industrial sites with spreader stoker boilers combined with a B-rated particulate emission factor. Based on the limited number of sites, CSSEF is D-rated.

The size distribution for wet scrubber controlled emissions from spreader stoker boilers was averaged from only eight sets of size distribution data from two sites combined with an estimated particulate emission factor. Although the size distribution data is A-quality, the sites are probably not fully representative of the industry since each site has flyash reinjection from multiple cyclones upstream of the wet scrubber. Predicated on the limited sampling, the CSSEF is D-rated.

Wood/Bark-Fired Systems

The CSSEF for uncontrolled emissions from a wood plus bark-fired underfeed stoker boiler system was developed by averaging two C-quality size distribution data sets from two industrial sites combined with a C-rated particulate emissions factor. This limited sampling only warrants an E-rated CSSEF.

The CSSEF for multiple-cyclone-controlled emissions with flyash reinjection from a wood plus bark-fired system was calculated using 3 A-quality data sets from one site combined with a C-rated particulate emission factor. The number of data sets and sampled sites is insufficient and the particulate emission factor is too low so that the resultant CSSEF is rated as E-quality.

The CSSEF for multiple-cyclone-controlled emissions from a wood plus bark-fired system was calculated using four B-quality size distribution data sets from one spreader stoker boiler combined with a C-rated particulate emission factor. The limited number of size distribution data sets and sites plus the low rating of the particulate emission factor results in an E-rating for the CSSEF.

The CSSEF for wet scrubber controlled emissions from a wood plus bark-fired system was calculated from 1 set of C-ranked data from each of two Dutch oven boiler test sites combined with an estimated particulate emission factor. The limited low-quality data results in CSSEF with an E-rating.

The size distribution for dry electrostatic granular filter-controlled emissions was calculated from three A-quality data sets from each of three modules located on the same boiler combined with a particulate emission factor derived from experimental data. Since the number of dry electrostatic granular filters in operation on wood plus bark-fired boilers is extremely limited, the particulate emission factor and CSSEF are both rated A.

Due to the nonavailability of data for all boiler types, size distribution estimates need to be made. The estimates are suggested as follows:

Firing configuration	Suggested approximation
Bark fired	
Multiple cyclones without flyash reinjection	Use size distribution for wood/bark
Wood -- no controls	Use size distribution for wood/bark

Valid size distribution data, when obtained, negates the requirement to use these approximations.

The cumulative size distribution and particulate emission factors used in the development of cumulative size-specific emission factors for wood waste combustion in boilers are shown in Table 60.

Although limited particle size distribution data was available for the following catagories, CSSEFs were not calculated due to insufficient data to calculate representative total mass particulate emission factors:

Firing Configuration

Wood/Bark

- No controls -- fluidized bed combustor with heat recovery boiler
- No controls -- salt laden fuel in spreader stoker boiler
- Multiple cyclones with flyash reinjection -- salt laden fuel in spreader stoker boiler
- Multiple cyclones with no flyash reinjection -- salt laden fuel in Dutch oven boiler
- Baghouse controlled -- salt laden fuel in Dutch oven boiler

3.5.5 Lignite

A summary of the data incorporated into each source and control device category for cumulative size specific emission factor development and its assigned rating follows.

TABLE 60. CUMULATIVE SIZE DISTRIBUTION AND PARTICULATE EMISSION FACTORS USED IN THE DEVELOPMENT OF CUMULATIVE SIZE-SPECIFIC EMISSION FACTORS FOR WOOD WASTE COMBUSTION IN BOILERS

Source category	Controls	Cumulative mass percent less than stated size							Size distribution data sets		Particulate emission factor (kg/Mg of fuel, as fired)	Cumulative size-specific emission factor rating
		0.625 μm	1 μm	1.25 μm	2.5 μm	6 μm	10 μm	15 μm	Number reviewed	Number used in average		
Bark fired	None[a]	9	13	15	21	28	35	42	11	11	24.0	D
	Multiple cyclones with flyash reinjection[a]	15	21	26	40	64	79	90	9	9	7.0	D
	Multiple cyclones without reinjection	Use size distribution for wood bark							0	0	4.5	--
	Scrubber[a]	14	23	29	56	78	87	92	8	8	1.44	D
Wood-bark	None[a]	--	67	69	76	86	90	94	2	2	3.6	E
	Multiple cyclones with flyash reinjection[a]	38	46	48	57	71	79	84	18	18	3.0	E
	Multiple cyclones without flyash reinjection[a]	3	6	8	16	27	32	35	4	4	2.7	E
	Scrubber[b]	--	95	96	98	98	98	98	2	2	0.22	E
	Dry electrostatic granular filter	51	58	61	65	69	74	77	9	9	0.16	A
Wood	None	Use size distribution for wood bark							--	--	4.4	--

[a] Listed controls applied to spreader stoker boilers.
[b] Listed controls applied to Dutch oven boilers.

Pulverized-Lignite-Fired Systems

The CSSEF for uncontrolled emissions from a pulverized-lignite-fired system was calculated using only two C-ranked size distribution data sets from one site combined with an A-rated particulate emission factor. Due to the low quality and quantity of size distribution data, the CSSEF is rated as E.

The CSSEF for multiple-cyclone-controlled emissions from a pulverized-lignite-fired system was developed based on only four sets of C-ranked data combined with an estimated particulate emission factor. Due to the low data quality input into the average, the CSSEP warrants only an E-quality rating.

Stoker Units

The CSSEF for multiple-cyclone-controlled emissions from a spreader-stoker-fed, lignite-fueled boiler was obtained from one C-ranked size distribution data set combined with an estimated particulate emission factor. The CSSEF only has an E-quality rating.

Due to the nonavailability of data for all boiler types, size distribution estimates need to be made. The estimates are suggested as follows:

Firing configuration	Suggested approximation
Cyclone furnace	Use size distribution for bituminous coal
Spreader stoker	Use size distribution for bituminous coal
Other stokers	Use size distribution for bituminous coal

Valid size distribution data, when obtained, negates the requirement to use these approximations.

The cumulative size distributions and particulate emission factors used in the development of cumulative size-specific emission factors for lignite coal combustion are shown in Table 61.

Table 61. CUMULATIVE SIZE DISTRIBUTION AND PARTICULATE EMISSION FACTORS USED IN THE DEVELOPMENT OF SIZE-SPECIFIC EMISSION FACTORS FOR LIGNITE COAL COMBUSTION

Firing configuration	Controls	Cumulative mass percent less than stated size							Size disbribution data sets		Particulate emission factor (kg/Mg of coal, as fired)	Cumulative size-specific emission factor rating
		0.625 μm	1 μm	1.25 μm	2.5 μm	6 μm	10 μm	15 μm	Number reviewed	Number used in average		
Pulverized coal-fired dry bottom	None	3	6	7	10	26	35	51	2	2	3.1A[a]	E
	Multiple cyclones	8	14	16	27	57	67	77	4	4	0.62A	E
Cyclone furnace	None	Use size distribution for bituminous coal							0	0	3.3A	--
Spreader stoker	None	Use size distribution for bituminous coal							0	0	3.4A	--
	Multiple cyclones	--	22	23	26	31	41	55	1	1	0.68A	E
Other stokers	None	Use size distribution for bituminous coal							0	0	1.5A	--

[a] A is ash content on an as-fired weight percent basis.

PROPOSED AP-42 SECTIONS

The proposed revision to Sections 1.1, 1.2, 1.3, 1.4, 1.6 and 1.7 of AP-42 is presented in the following pages as it would appear in the actual document.

1.1 BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

1.1.1 General[1]

Coal is a complex combination of organic matter and inorganic ash formed over eons from successive layers of fallen vegetation. Coal types are broadly classified as anthracite, bituminous, subbituminous or lignite, and classification is made by heating values and amounts of fixed carbon, volatile matter, ash, sulfur and moisture. Formulas for differentiating coals based on these properties are given in Reference 1. See Sections 1.2 and 1.7 for discussions of anthracite and lignite, respectively.

There are two major coal combustion techniques, suspension firing and grate firing. Suspension firing is the primary combustion mechanism in pulverized coal and cyclone systems. Grate firing is the primary mechanism in underfeed and overfeed stokers. Both mechanisms are employed in spreader stokers.

Pulverized coal furnaces are used primarily in utility and large industrial boilers. In these systems, the coal is pulverized in a mill to the consistency of talcum powder (i. e., at least 70 percent of the particles will pass through a 200 mesh sieve). The pulverized coal is generally entrained in primary air before being fed through the burners to the combustion chamber, where it is fired in suspension. Pulverized coal furnaces are classified as either dry or wet bottom, depending on the ash removal technique. Dry bottom furnaces fire coals with high ash fusion temperatures, and dry ash removal techniques are used. In wet bottom (slag tap) furnaces, coals with low ash fusion temperatures are used, and molten ash is drained from the bottom of the furnace. Pulverized coal furnaces are further classified by the firing position of the burners, i. e., single (front or rear) wall, horizontally opposed, vertical, tangential (corner fired), turbo or arch fired.

Cyclone furnaces burn low ash fusion temperature coal crushed to a 4 mesh size. The coal is fed tangentially, with primary air, to a horizontal cylindrical combustion chamber. In this chamber, small coal particles are burned in suspension, while the larger particles are forced against the outer wall. Because of the high temperatures developed in the relatively small furnace volume, and because of the low fusion temperature of the coal ash, much of the ash forms a liquid slag which is drained from the bottom of the furnace through a slag tap opening. Cyclone furnaces are used mostly in utility and large industrial applications.

In spreader stokers, a flipping mechanism throws the coal into the furnace and onto a moving fuel bed. Combustion occurs partly in suspension and partly on the grate. Because of significant carbon in the particulate, flyash reinjection from mechanical collectors is commonly employed to improve boiler efficiency. Ash residue in the fuel bed is deposited in a receiving pit at the end of the grate.

TABLE 1.1-1. EMISSION FACTORS FOR EXTERNAL BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION[a]

Firing Configuration	Particulate[b]		Sulfur Oxides[c]		Nitrogen Oxides[d]		Carbon Monoxide[e]		Nonmethane VOC[e,f]		Methane[e]	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Pulverized coal fired Dry bottom	5A	10A	19.5S(17.5S)	39S(35S)	10.5(7.5)[g]	21(15)[g]	0.3	0.6	0.04	0.07	0.015	0.03
Wet bottom	3.5A[h]	7A[h]	19.5S(17.5S)	39S(35S)	17	34	0.3	0.6	0.04	0.07	0.015	0.03
Cyclone furnace	1A[h]	2A[h]	19.5S(17.5S)	39S(35S)	18.5	37	0.3	0.6	0.04	0.07	0.015	0.03
Spreader stoker Uncontrolled	30[j]	60[j]	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
After multiple cyclone With fly ash reinjection from multiple cyclone	8.5	17	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
No fly ash reinjection from multiple cyclone	6	12	19.5S(17.5S)	39S(35S)	7	14	2.5	5	0.04	0.07	0.015	0.03
Overfeed stoker[k] Uncontrolled	8[m]	16[m]	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
After multiple cyclone	4.5[n]	9[n]	19.5S(17.5S)	39S(35S)	3.25	7.5	3	6	0.04	0.07	0.015	0.03
Underfeed stoker Uncontrolled	7.5[p]	15[p]	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
After multiple cyclone	5.5[n]	11[n]	15.5S	31S	4.75	9.5	5.5	11	0.65	1.3	0.4	0.8
Handfired units	7.5	15	15.5S	31S	1.5	3	45	90	5	10	4	8

[a] Factors represent uncontrolled emissions unless otherwise specified and should be applied to coal consumption as fired.

[b] Based on EPA Method 5 (front half catch) as described in Reference 12. Where particulate is expressed in terms of coal ash content, A, factor is determined by multiplying weight % ash content of coal (as fired) by the numerical value preceding the "A". For example, if coal having 8% ash is fired in a dry bottom unit, the particulate emission factor would be 5 x 8, or 40 kg/Mg (80 lb/ton). The "condensible" matter collected in back half catch of EPA Method 5 averages <5% of front half, or "filterable", catch for pulverized coal and cyclone furnaces; 10% for spreader stokers; 15% for other stokers; and 50% for handfired units (References 6, 19, 49).

[c] Expressed as SO_2, including SO_2, SO_3 and gaseous sulfates. Factors in parentheses should be used to estimate gaseous SO_x emissions for subbituminous coal. In all cases, "S" is weight % sulfur content of coal as fired. See Footnote b for example calculation. On average for bituminous coal, 97% of fuel sulfur is emitted as SO_2, and only about 0.7% of fuel sulfur is emitted as SO_3 and gaseous sulfate. An equally small percent of fuel sulfur is emitted as particulate sulfate (References 9, 13). Small quantities of sulfur are also retained in bottom ash. With subbituminous coal generally about 10% more fuel sulfur is retained in the bottom ash and particulate because of the more alkaline nature of the coal ash. Conversion to gaseous sulfate appears about the same as for bituminous coal.

[d] Expressed as NO_2. Generally, 95 - 99 volume % of nitrogen oxides present in combustion exhaust will be in the form of NO, the rest NO_2 (Reference 11). To express factors as NO, multiply by factor of 0.66. All factors represent emission at baseline operation (i.e., 60 - 110% load and no NO_x control measures, as discussed in text).

[e] Nominal values achieveable under normal operating conditions. Values one or two orders of magnitude higher can occur when combustion is not complete.

[f] Nonmethane volatile organic compounds (VOC), expressed as C_2 to C_{16} n-alkane equivalents (Reference 58). Because of limited data on NMVOC available to distinguish the effects of firing configuration, all data were averaged collectively to develop a single average for pulverized coal units, cyclones, spreaders and overfeed stokers.

[g] Parenthetic value is for tangentially fired boilers.

[h] Uncontrolled particulate emissions, when no fly ash reinjection is employed. When control device is installed, and collected fly ash is reinjected to boiler, particulate from boiler reaching control equipment can increase by up to a factor of two.

[j] Accounts for fly ash settling in an economizer, air heater or breaching upstream of control device or stack. (Particulate directly at boiler outlet typically will be twice this level.) Factor should be applied even when fly ash is reinjected to boiler from boiler, air heater or economizer dust hoppers.

[k] Includes traveling grate, vibrating grate and chain grate stokers.

[m] Accounts for fly ash settling in breaching or stack base. Particulate loadings directly at boiler outlet typically can be 50% higher.

[n] See text for discussion of apparently low multiple cyclone control efficiencies, regarding uncontrolled emissions.

[p] Accounts for fly ash settling in breaching downstream of boiler outlet.

TABLE 1.1-2. EMISSION FACTOR RATINGS* AND REFERENCES FOR BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION

Firing Configuration	Particulate		Sulfur Oxides		Nitrogen Oxides		Carbon Monoxide		Nonmethane VOC		Methane	
	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.	Rating	Ref.
Pulverized coal fired Dry bottom	A	14-25	A	9,16-19,21, 31-37,39, 41-46,51-55	A	11,14,16-17, 21,46,56	A	16,18-19,21 47,57	A	55,58	A	58
Wet bottom	D	14,16,26	A	"	C	14,16	A	"	A	58	A	"
Cyclone furnace	D	14,19,22, 27-29	A	"	B	11	A	"	A	"	A	"
Spreader stoker Uncontrolled	B	17,30-35	A	"	A	11,17,31-37 39-40,46	A	17,19,31-34, 36,47,51	A	"	A	"
After multiple cyclone With flyash reinjection from cyclone	B	14,32,36-38	A	"	A	"	A	"	A	"	A	"
No flyash reinjection from cyclone	A	17,31-35, 39,40,59	A	"	A	"	A	"	A	"	A	"
Overfeed stoker Uncontrolled	B	6,17,41-43, 45-47	A	"	A	11,17,19, 41-45	B	17,41-42,45, 47,51	A	"	A	"
After multiple cyclone	B	6,41,44-45	A	"	A	"	B	"	A	"	A	"
Underfeed stoker Uncontrolled	B	6,19,47-48	B	19,48	B	19,47-48	B	19,47-48	A	47,58	A	47,58
After multiple cyclone	C	6	B	"	B	"	B	"	A	"	A	"
Handfired units	D	49-50	D	"	D	50	D	50	D	50,58	D	50,58

*These ratings, in the context of this Section, refer to the number of test data on which each emission factor is based. An "A" rating means the factor is based on tests at ten or more boilers, a "B" rating on six to nine test data, and a "C" rating on test data for two to five boilers. A "D" rating indicates the factor is based on only a single datum or extrapolated from a secondary reference. These ratings are not a measure of the scatter in the underlying test data. However, a higher rating will generally increase confidence that a given factor will better approximate the average emissions for a particular boiler category.

In overfeed stokers, coal is fed onto a traveling or vibrating grate, and it burns on the fuel bed as it progresses through the furnace. Ash particles fall into an ash pit at the rear of the stoker. The term "overfeed" applies because the coal is fed onto the moving grate under an adjustable gate. Conversely, in "underfeed" stokers, coal is fed into the firing zone from underneath by mechanical rams or screw conveyers. The coal moves in a channel, known as a retort, from which it is forced upward, spilling over the top of each side to form and to feed the fuel bed. Combustion is completed by the time the bed reaches the side dump grates from which the ash is discharged to shallow pits. Underfeed stokers include single retort units and multiple retort units, the latter having several retorts side by side.

1.1.2 Emissions And Controls

The major pollutants of concern from external coal combustion are particulate, sulfur oxides and nitrogen oxides. Some unburnt combustibles, including numerous organic compounds and carbon monoxide, are generally emitted even under proper boiler operating conditions.

Particulate[2-4] - Particulate composition and emission levels are a complex function of firing configuration, boiler operation and coal properties. In pulverized coal systems, combustion is almost complete, and thus particulate largely comprises inorganic ash residue. In wet bottom pulverized coal units and cyclones, the quantity of ash leaving the boiler is less than in dry bottom units, since some of the ash liquifies, collects on the furnace walls, and drains from the furnace bottom as molten slag. To increase the fraction of ash drawn off as wet slag, and thus to reduce the flyash disposal problem, flyash may be reinjected from collection equipment into slag tap systems. Dry bottom unit ash may also be reinjected into wet bottom boilers for the same purpose.

Because a mixture of fine and coarse coal particles is fired in spreader stokers, significant unburnt carbon can be present in the particulate. To improve boiler efficiency, flyash from collection devices (typically multiple cyclones) is sometimes reinjected into spreader stoker furnaces. This practice can dramatically increase the particulate loading at the boiler outlet and, to a lesser extent, at the mechanical collector outlet. Flyash can also be reinjected from the boiler, air heater and economizer dust hoppers. Flyash reinjection from these hoppers does not increase particulate loadings nearly so much as from multiple cyclones.[5]

Uncontrolled overfeed and underfeed stokers emit considerably less particulate than do pulverized coal units and spreader stokers, since combustion takes place in a relatively quiescent fuel bed. Flyash reinjection is not practiced in these kinds of stokers.

Other variables than firing configuration and flyash reinjection can affect emissions from stokers. Particulate loadings will often increase as load increases (especially as full load is approached) and with sudden load changes. Similarly, particulate can increase as the ash and fines contents increase. ("Fines", in this context, are coal particles smaller than about 1.6 millimeters, or one sixteenth inch, in diameter.) Conversely, particulate can be reduced significantly when overfire air pressures are increased.[5]

The primary kinds of particulate control devices used for coal combustion include multiple cyclones, electrostatic precipitators, fabric filters (baghouses) and scrubbers. Some measure of control will even result from ash settling in boiler/air heater/economizer dust hoppers, large breeches and chimney bases. To the extent possible from the existing data base, the effects of such settling are reflected in the emission factors in Table 1.1-1.

Electrostatic precipitators (ESP) are the most common high efficiency control device used on pulverized coal and cyclone units, and they are being used increasingly on stokers. Generally, ESP collection efficiencies are a function of collection plate area per volumetric flow rate of flue gas through the device. Particulate control efficiencies of 99.9 weight percent are obtainable with ESPs. Fabric filters have recently seen increased use in both utility and industrial applications, generally effecting about 99.8 percent efficiency. An advantage of fabric filters is that they are unaffected by high flyash resistivities associated with low sulfur coals. ESPs located after air preheaters (i. e., cold side precipitators) may operate at significantly reduced efficiencies when low sulfur coal is fired. Scrubbers are also used to control particulate, although their primary use is to control sulfur oxides. One drawback of scrubbers is the high energy requirement to achieve control efficiencies comparable to those of ESPs and baghouses.[2]

Mechanical collectors, generally multiple cyclones, are the primary means of control on many stokers and are sometimes installed upsteam of high efficiency control devices in order to reduce the ash collection burden. Depending on application and design, multiple cyclone efficiencies can vary tremendously. Where cyclone design flow rates are not attained (which is common with underfeed and overfeed stokers), these devices may be only marginally effective and may prove little better in reducing particulate than large breeching. Conversely, well designed multiple cyclones, operating at the required flow rates, can achieve collection efficiencies on spreader stokers and overfeed stokers of 90 to 95 percent. Even higher collection efficiencies are obtainable on spreader stokers with reinjected flyash, because of the larger particle sizes and increased particulate loading reaching the controls.[5-6]

Sulfur Oxides[7-9] - Gaseous sulfur oxides from external coal combustion are largely sulfur dioxide (SO_2) and much less quantity of sulfur trioxide (SO_3) and gaseous sulfates. These compounds form as the organic and pyritic sulfur in the coal is oxidized during the combustion process. On average, 98 percent of the sulfur present in bituminous coal will be emitted as gaseous sulfur oxides, whereas somewhat less will be emitted when subbituminous coal is fired. The more alkaline nature of the ash in some subbituminous coal causes some of the sulfur to react to form various sulfate salts that are retained in the boiler or in the flyash. Generally, boiler size, firing configuration and boiler operations have little effect on the percent conversion of fuel sulfur to sulfur oxides.

Several techniques are used to reduce sulfur oxides from coal combustion. One way is to switch to lower sulfur coals, since sulfur oxide emissions are proportional to the sulfur content of the coal. This alternative may not be possible where lower sulfur coal is not readily available or where a different grade of coal can not be satisfactorily fired. In some cases, various cleaning processes may be employed to reduce the fuel sulfur content. Physical coal cleaning removes mineral sulfur such as pyrite but is not effective in removing organic sulfur. Chemical cleaning and solvent refining processes are being developed to remove organic sulfur.

Many flue gas desulfurization techniques can remove sulfur oxides formed during combustion. Flue gases can be treated through wet, semidry or dry desulfurization processes of either the throwaway type, in which all waste streams are discarded, or the recovery (regenerable) type, in which the SO_x absorbent is regenerated and reused. To date, wet systems are the most commonly applied. Wet systems generally use alkali slurries as the SO_x absorbent medium and can be designed to remove well in excess of 90 percent of the incoming SO_x. Particulate reduction of up to 99 percent is also possible with wet scrubbers, but flyash is often collected by upsteam ESPs or baghouses, to avoid erosion of the desulfurization equipment and possible interference with the process reactions.[7] Also, the volume of scrubber sludge is reduced with separate flyash removal, and contamination of the reagents and byproducts is prevented. References 7 and 8 give more details on scrubbing and other SO_x removal techniques.

Nitrogen Oxides [10-11] - Nitrogen oxides (NO_x) emissions from coal combustion are primarily nitrogen oxide (NO). Only a few volume percent are nitrogen dioxide (NO_2). NO results from thermal fixation of atmospheric nitrogen in the combustion flame and from oxidation of nitrogen bound in the coal. Typically, only 20 to 60 percent of the fuel nitrogen is converted to nitrogen oxides. Bituminous and subbituminous coals usually contain from 0.5 to 2 weight percent nitrogen, present mainly in aromatic ring structures. Fuel nitrogen can account for up to 80 percent of total NO_x from coal combustion.

A number of combustion modifications can be made to reduce NO_x emissions from boilers. Low excess air (LEA) firing is the most widespread control modification, because it can be practiced in both old and new units and in all sizes of boilers. LEA firing is easy to implement and has the added advantage of increasing fuel use efficiency. LEA firing is generally effective only above 20 percent excess air for pulverized coal units and above 30 percent excess air for stokers. Below these levels, the NO_x reduction from decreased O_2 availability is offset by increased NO_x because of increased flame temperature. Another NO_x reduction technique is simply to switch to a coal having a lower nitrogen content, although many boilers may not properly fire coals of different properties.

Off-stoichiometric (staged) combustion is also an effective means of controlling NO_x from coal fired equipment. This can be achieved by using overfire air or low NO_x burners designed to stage combustion in the flame zone. Other NO_x reduction techniques include flue gas recirculation, load reduction, and steam or water injection. However, these techniques are not very effective for use on coal fired equipment because of the fuel nitrogen effect. Ammonia injection is another technique which can be used, but it is costly. The net reduction of NO_x from any of these techniques or combinations thereof varies considerably with boiler type, coal properties and existing operating practices. Typical reductions will range from 10 to 60 percent. References 10 and 60 should be consulted for a detailed discussion of each of these NO_x reduction techniques. To date, flue gas treatment is not used to reduce nitrogen oxide emissions because of its higher cost.

Volatile Organic Compounds And Carbon Monoxide - Volatile organic compounds (VOC) and carbon monoxide (CO) are unburnt gaseous combustibles which generally are emitted in quite small amounts. However, during startups, temporary upsets or other conditions preventing complete combustion, unburnt combustible emissions may increase dramatically. VOC and CO emissions per unit of fuel fired are normally lower from pulverized coal or cyclone furnaces than from smaller stokers and handfired units where operating conditions are not so well controlled. Measures used for NO_x control can increase CO emissions, so to reduce the risk of explosion, such measures are applied only to the point at which CO in the flue gas reaches a maximum of about 200 parts per million. Other than maintaining proper combustion conditions, control measures are not applied to control VOC and CO.

Emission Factors And References - Emission factors for several pollutants are presented in Table 1.1-1, and factor ratings and references are presented in Table 1.1-2. The factors for uncontrolled underfeed stokers and hand fired units also may be applied to hot air furnaces. Tables 1.1-3 through 1.1-8 present cumulative size distribution data and size specific emission factors for particulate emissions from the combustion sources discussed above. Uncontrolled and controlled size specific emission factors are presented in Figures 1.1-1 through 1.1-6.

TABLE 1.1-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRY BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled)
D (scrubber and ESP controlled
E (multiple cyclone and baghouse)

Particle size[b] (µm)	Cumulative mass % ≤ stated size					Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]				
	Uncontrolled	Controlled				Uncontrolled	Controlled[d]			
		Multiple cyclone	Scrubber	ESP	Baghouse		Multiple cyclone	Scrubber	ESP	Baghouse
15	32	54	81	79	97	1.6A (3.2A)	0.54A (1.08A)	0.24A (0.48A)	0.032A (0.06A)	0.010A (0.02A)
10	23	29	71	67	92	1.15A (2.3A)	0.29A (0.58A)	0.21A (0.42A)	0.027A (0.05A)	0.009A (0.02A)
6	17	14	62	50	77	0.85A (1.7A)	0.14A (0.28A)	0.19A (0.38A)	0.020A (0.04A)	0.008A (0.02A)
2.5	6	3	51	29	53	0.30A (0.6A)	0.03A (0.06A)	0.15A (0.3A)	0.012A (0.02A)	0.005A (0.01A)
1.25	2	1	35	17	31	0.10A (0.2A)	0.01A (0.02A)	0.11A (0.22A)	0.007A (0.01A)	0.003A (0.006A)
1.00	2	1	31	14	25	0.10A (0.2A)	0.01A (0.02A)	0.09A (0.18A)	0.006A (0.01A)	0.003A (0.006A)
0.625	1	1	20	12	14	0.05A (0.10)	0.01A (0.02A)	0.06A (0.12A)	0.005A (0.01A)	0.001A (0.002A)
TOTAL	100	100	100	100	100	5A (10A)	1A (2A)	0.3A (0.6A)	0.04A (0.08A)	0.01A (0.02A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%; scrubber, 94%; ESP, 99.2%; baghouse, 99.8%.

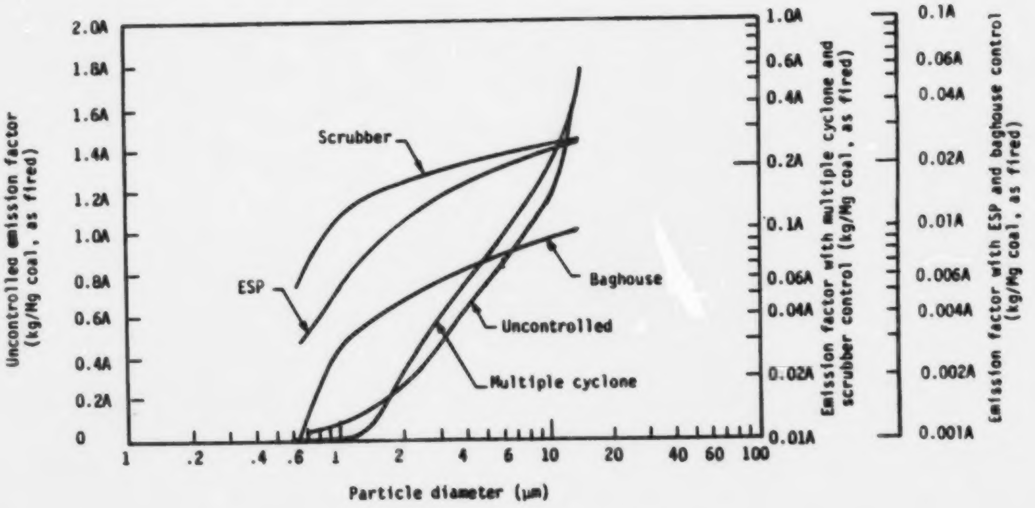

Figure 1.1-1. Cumulative size specific emission factors for dry bottom boilers burning pulverized bituminous coal.

TABLE 1.1-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR WET BOTTOM BOILERS BURNING PULVERIZED BITUMINOUS COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (μm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		Multiple cyclone	ESP		Multiple cyclone	ESP
15	40	99	83	1.4A (2.8A)	0.69A (1.38A)	0.023A (0.046A)
10	37	93	75	1.30A (2.6A)	0.65A (1.3A)	0.021A (0.042A)
6	33	84	63	1.16A (2.32A)	0.59A (1.18A)	0.018A (0.036A)
2.5	21	61	40	0.74A (1.48A)	0.43A (0.86A)	0.011A (0.022A)
1.25	6	31	17	0.21A (0.42A)	0.22A (0.44A)	0.005A (0.01A)
1.00	4	19	8	0.14A (0.28A)	0.13A (0.26A)	0.002A (0.004A)
0.625	2	e	e	0.07A (0.14A)	e	e
TOTAL	100	100	100	3.5A (7.0A)	0.7A (1.4A)	0.028A (0.056A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%; ESP, 99.2%.
[e] Insufficient data.

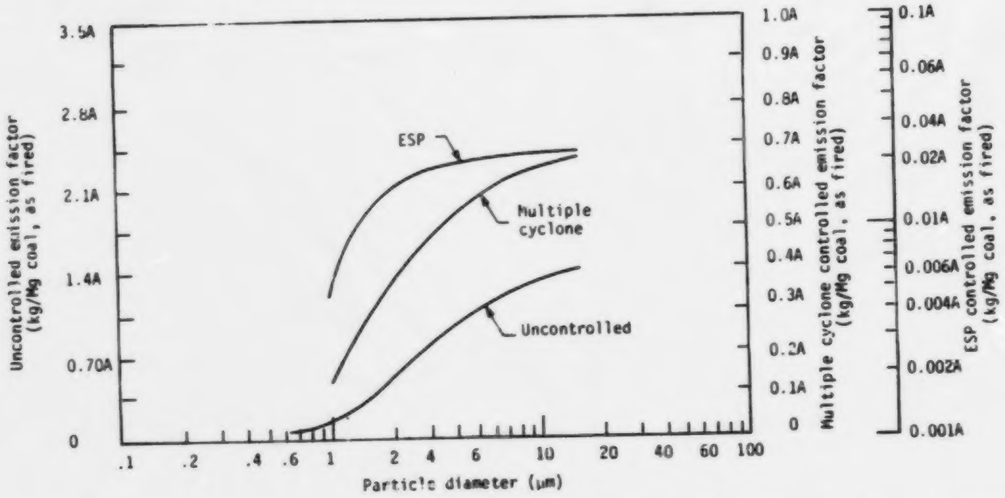

Figure 1.1-2. Cumulative size specific emission factors for wet bottom boilers burning pulverized bituminous coal

TABLE 1.1-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR CYCLONE FURNACES BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (µm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[e]	
		Scrubber	ESP		Scrubber	ESP
15	33	95	90	0.33A (0.66A)	0.057A (0.114A)	0.0064A (0.013A)
10	13	94	68	0.13A (0.26A)	0.056A (0.112A)	0.0054A (0.011A)
6	8	93	56	0.08A (0.16A)	0.056A (0.112A)	0.0045A (0.009A)
2.5	0	92	36	0 (0)	0.055A (0.11A)	0.0029A (0.006A)
1.25	0	85	22	0 (0)	0.051A (0.10A)	0.0018A (0.004A)
1.00	0	82	17	0 (0)	0.049A (0.10A)	0.0014A (0.003A)
0.625	0	d	d	0 (0)	d	d
TOTAL	100	100	100	1A (2A)	0.06A (0.12A)	0.008A (0.016A)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight %, as fired.
[d] Insufficient data.
[e] Estimated control efficiency for scrubber, 94%; ESP, 99.2%.

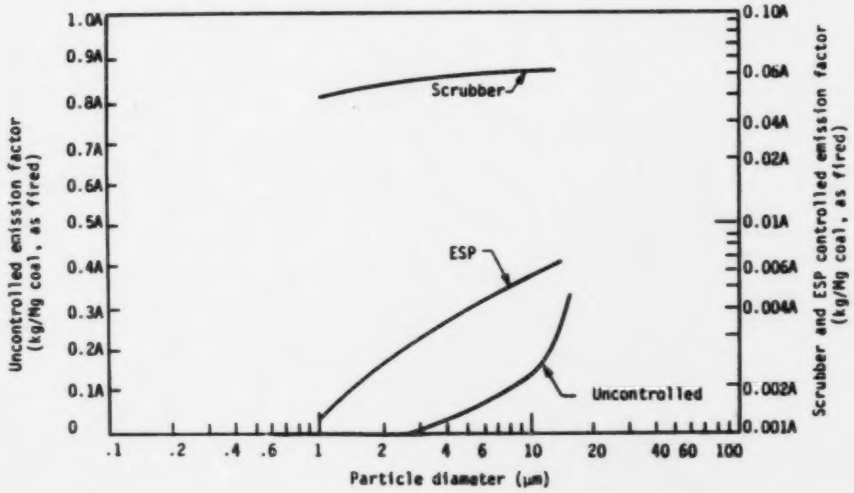

Figure 1.1-3. Cumulative size specific emission factors for cyclone furnaces burning bituminous coal

TABLE 1.1-6. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR SPREADER STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled and controlled for multiple cyclone without flyash reinjection, and with baghouse)
E (multiple cyclone controlled with flyash reinjection, and ESP controlled)

Particle size[b] (µm)	Cumulative mass % ≤ stated size					Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]				
	Uncontrolled	Controlled				Uncontrolled	Controlled			
		Multiple cyclone[c]	Multiple cyclone[d]	ESP	Baghouse		Multiple cyclone[c]	Multiple cyclone[d]	ESP	Baghouse
15	28	86	74	97	72	8.4 (16.8)	7.3 (14.6)	4.4 (8.8)	0.23 (0.46)	0.043 (0.086)
10	20	73	65	90	60	6.0 (12.0)	6.2 (12.4)	3.9 (7.8)	0.22 (0.44)	0.036 (0.072)
6	14	51	52	82	46	4.2 (8.4)	4.3 (8.6)	3.1 (6.2)	0.20 (0.40)	0.028 (0.056)
2.5	7	8	27	61	26	2.1 (4.2)	0.7 (1.4)	1.6 (3.2)	0.15 (0.30)	0.016 (0.032)
1.25	5	2	16	46	18	1.5 (3.0)	0.2 (0.4)	1.0 (2.0)	0.11 (0.22)	0.011 (0.022)
1.00	5	2	14	41	15	1.5 (3.0)	0.2 (0.4)	0.8 (1.6)	0.10 (0.20)	0.009 (0.018)
0.625	4	1	9	e	7	1.2 (2.4)	0.1 (0.2)	0.5 (1.0)	e	0.004 (0.008)
TOTAL	100	100	100	100	100	30.0 (60.0)	8.5 (17.0)	6.0 (12.0)	0.24 (0.48)	0.06 (0.12)

[a] Reference 61. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] With flyash reinjection.
[d] Without flyash reinjection.
[e] Insufficient data.
[f] Estimated control efficiency for ESP, 99.2%; baghouse, 99.8%.

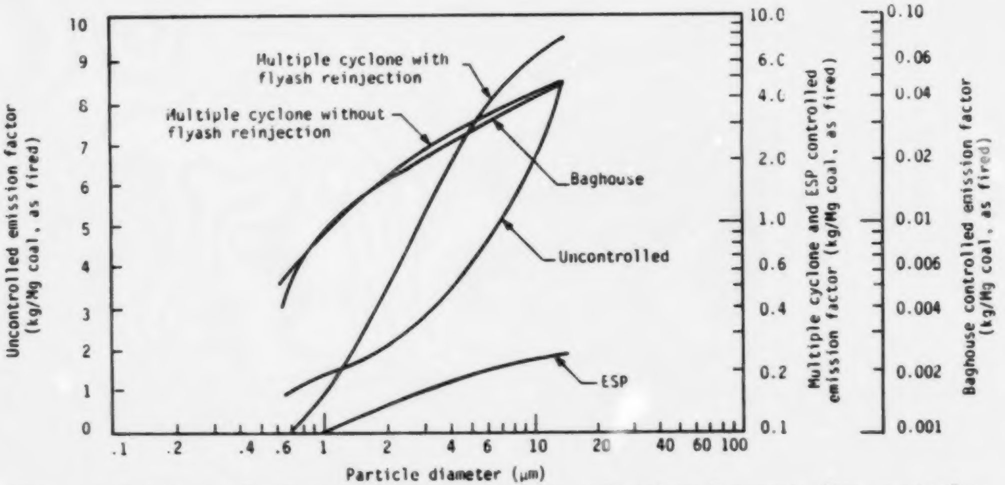

Figure 1.1-4. Cumulative size specific emission factors for spreader stokers burning bituminous coal

TABLE 1.1-7. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR OVERFEED STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C (uncontrolled)
E (multiple cyclone controlled)

Particle size[b] (μm)	Cumulative mass % ≤ stated size		Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[d]
15	49	60	3.9 (7.8)	2.7 (5.4)
10	37	55	3.0 (6.0)	2.5 (5.0)
6	24	49	1.9 (3.8)	2.2 (4.4)
2.5	14	43	1.1 (2.2)	1.9 (3.8)
1.25	13	39	1.0 (2.0)	1.8 (3.6)
1.00	12	39	1.0 (2.0)	1.8 (3.6)
0.625	c	16	c	0.7 (1.4)
TOTAL	100	100	8.0 (16.0)	4.5 (9.0)

[a] Reference 61.
[b] Expressed as aerodynamic equivalent diameter.
[c] Insufficient data.
[d] Estimated control efficiency for multiple cyclone, 80%.

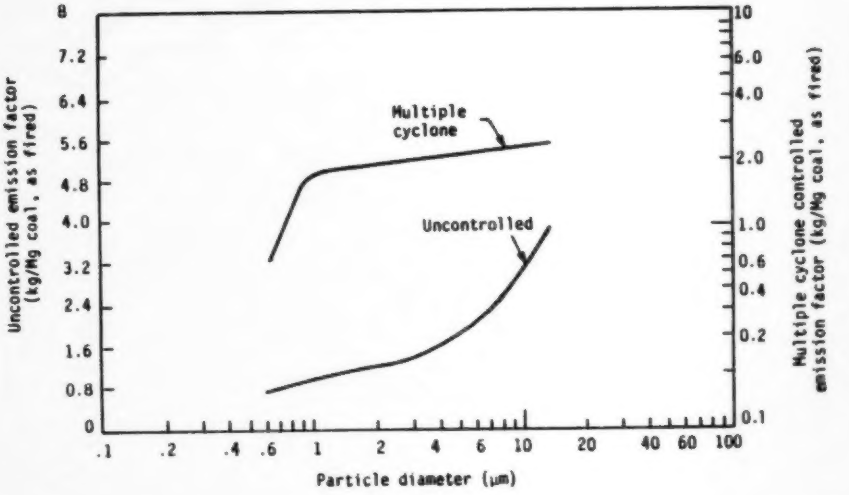

Figure 1.1-5. Cumulative size specific emission factors for overfeed stokers burning bituminous coal

TABLE 1.1-8. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNDERFEED STOKERS BURNING BITUMINOUS COAL[a]

EMISSION FACTOR RATING: C

Particle size[b] (μm)	Cumulative mass % ≤ stated size	Uncontrolled cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]
15	50	3.8 (7.6)
10	41	3.1 (6.2)
6	32	2.4 (4.8)
2.5	25	1.9 (3.8)
1.25	22	1.7 (3.4)
1.00	21	1.6 (3.2)
0.625	18	1.4 (2.7)
TOTAL	100	7.5 (15.0)

[a] Reference 61.

[b] Expressed as aerodynamic equivalent diameter.

[c] May also be used for uncontrolled hand fired units.

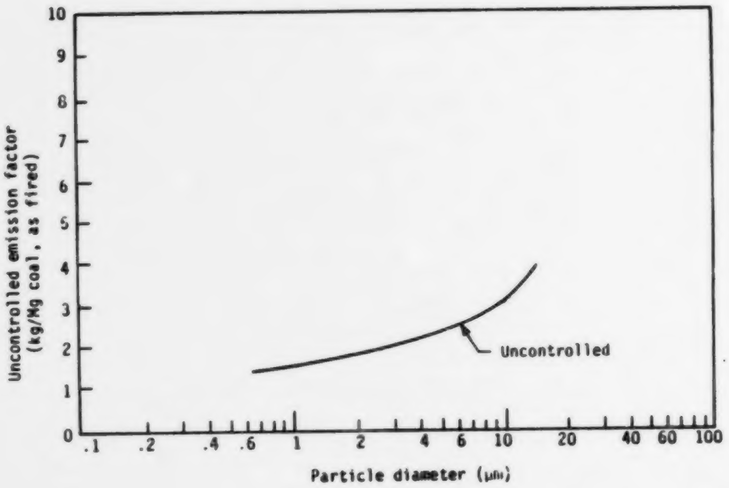

Figure 1.1-6. Cumulative size specific emission factors for underfeed stokers burning bituminous coal.

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1.2 ANTHRACITE COAL COMBUSTION

1.2.1 General[1-2]

Anthracite coal is a high rank coal with more fixed carbon and less volatile matter than either bituminous coal or lignite, and it has higher ignition and ash fusion temperatures. Because of its low volatile matter content and slight clinkering, anthracite is most commonly fired in medium sized traveling grate stokers and small hand fired units. Some anthracite (occasionally with petroleum coke) is used in pulverized coal fired boilers. It is also blended with bituminous coal. None is fired in spreader stokers. For its low sulfur content (typically less than 0.8 weight percent) and minimal smoking tendencies, anthracite is considered a desirable fuel where readily available.

In the United States, all anthracite is mined in northeastern Pennsylvania and is consumed mostly in Pennsylvania and several surrounding states. The largest use of anthracite is for space heating. Lesser amounts are employed for steam/electric production; coke manufacturing, sintering and pelletizing; and other industrial uses. Anthracite currently is only a small fraction of the total quantity of coal combusted in the United States.

1.2.2 Emissions And Controls[2-14]

Particulate emissions from anthracite combustion are a function of furnace firing configuration, firing practices (boiler load, quantity and location of underfire air, sootblowing, flyash reinjection, etc.), and the ash content of the coal. Pulverized coal fired boilers emit the highest quantity of particulate per unit of fuel because they fire the anthracite in suspension, which results in a high percentage of ash carryover into exhaust gases. Pulverized anthracite fired boilers operate in the dry tap or dry bottom mode, because of anthracite's characteristically high ash fusion temperature. Traveling grate stokers and hand fired units produce much less particulate per unit of fuel fired, because combustion takes place in a quiescent fuel bed without significant ash carryover into the exhaust gases. In general, particulate emissions from traveling grate stokers will increase during sootblowing and flyash reinjection and with higher fuel bed underfeed air from forced draft fans. Smoking is rarely a problem, because of anthracite's low volatile matter content.

Limited data are available on the emission of gaseous pollutants from anthracite combustion. It is assumed from bituminous coal combustion data that a large fraction of the fuel sulfur is emitted as sulfur oxides. Also, because combustion equipment, excess air rates, combustion temperatures, etc., are similar between anthracite and bituminous coal combustion, nitrogen oxide and carbon monoxide emissions are assumed to be similar, too. Volatile organic compound (VOC) emissions, however, are expected to be considerably lower, since the volatile matter content of anthracite is significantly less than that of bituminous coal.

TABLE 1.2-1. UNCONTROLLED EMISSION FACTORS FOR ANTHRACITE COMBUSTION[a]

Boiler type	Particulate[b]		Sulfur oxides[c]		Nitrogen oxides[d]		Carbon monoxide[e]		Volatile organics	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Nonmethane	Methane
Pulverized coal fired	f	f	19.5S	39S	9	18	f	f	f	f
Traveling grate stoker	4.6[g]	9.1[g]	19.5S	39S	5	10	0.3	0.6	f	f
Hand fed units	5[h]	10[h]	19.5S	39S	1.5	3	f	f	f	f

[a] Factors are for uncontrolled emissions and should be applied to coal consumption as fired.

[b] Based on EPA Method 5 (front half catch).

[c] Assumes, as with bituminous coal combustion, most fuel sulfur is emitted as SO_x. Limited data in Reference 5 verify this for pulverized anthracite fired boilers. Emissions are mostly SO_2, with 1 - 3% SO_3. S indicates that weight % sulfur should be multiplied by the value given.

[d] For pulverized anthracite fired boilers and hand fed units, assumed to be similar to bituminous coal combustion. For traveling grate stokers, see References 8, 11.

[e] May increase by several orders of magnitude with boilers not properly operated or maintained. For traveling grate stokers, based on limited information in Reference 8. For pulverized coal fired boilers, substantiated by additional data in Reference 14.

[f] Factors in Table 1.1-1 may be used, based on similarity of anthracite and bituminous coal.

[g] References 12-13, 15-18. Accounts for limited fallout that may occur in fallout chambers and stack breeching. Factors for individual boilers may be 2.5 - 25 kg/Mg (5 - 50 lb/ton), highest during soot blowing.

[h] Reference 2.

Controls on anthracite emissions mainly have been applied to particulate matter. The most efficient particulate controls, fabric filters, scrubbers and electrostatic precipitators, have been installed on large pulverized anthracite fired boilers. Fabric filters and venturi scrubbers can effect collection efficiencies exceeding 99 percent. Electrostatic precipitators typically are only 90 to 97 percent efficient, because of the characteristic high resistivity of low sulfur anthracite fly ash. It is reported that higher efficiencies can be achieved using larger precipitators and flue gas conditioning. Mechanical collectors are frequently employed upstream from these devices for large particle removal.

Traveling grate stokers are often uncontrolled. Indeed, particulate control has often been considered unnecessary, because of anthracite's low smoking tendencies and of the fact that a significant fraction of large size flyash from stokers is readily collected in flyash hoppers as well as in the breeching and base of the stack. Cyclone collectors have been employed on traveling grate stokers, and limited information suggests these devices may be up to 75 percent efficient on particulate. Flyash reinjection, frequently used in traveling grate stokers to enhance fuel use efficiency, tends to increase particulate emissions per unit of fuel combusted.

Emission factors for pollutants from anthracite coal combustion are given in Table 1.2-1, and factor ratings in Table 1.2-2. Cumulative size distribution data and size specific emission factors and ratings for particulate emissions are in Tables 1.2-3 and 1.2-4. Uncontrolled and controlled size specific emission factors are presented in Figures 1.2-1 and 1.2-2. Size distribution data for bituminous coal combustion may be used for uncontrolled emissions from pulverized anthracite fired furnaces, and data for anthracite fired traveling grate stokers may be used for hand fed units.

TABLE 1.2-2. ANTHRACITE COAL EMISSION FACTOR RATINGS

Furnace Type	Particulate	Sulfur oxides	Nitrogen oxides	Carbon monoxide	Volatile organics	
					Nonmethane	Methane
Pulverized coal	B	B	B	B	C	C
Traveling grate stoker	B	B	B	B	C	C
Hand fed units	B	B	B	B	D	D

TABLE 1.2-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR DRY BOTTOM BOILERS BURNING PULVERIZED ANTHRACITE COAL[a]

EMISSION FACTOR RATING: D

Particle size[b] (µm)	Cumulative mass % ≤ stated size			Cumulative emission factor[c] [kg/Mg (lb/ton) bark, as fired]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		Multiple cyclone	Baghouse		Multiple cyclone	Baghouse
15	32	63	79	1.6A (3.2A)	0.63A (1.26A)	0.0079A (0.016A)
10	23	55	67	1.2A (2.3A)	0.55A (1.10A)	0.0067A (0.013A)
6	17	46	51	0.9A (1.7A)	0.46A (0.92A)	0.0051A (0.010A)
2.5	6	24	32	0.3A (0.6A)	0.24A (0.48A)	0.0032A (0.006A)
1.25	2	13	21	0.1A (0.2A)	0.13A (0.26A)	0.0021A (0.004A)
1.00	2	10	18	0.1A (0.2A)	0.10A (0.20A)	0.0018A (0.004A)
0.625	1	7		0.05A (0.1A)	0.07A (0.14A)	e
TOTAL	100	100	100	5A (10A)	1A (2A)	0.01A (0.02A)

[a] Reference 19.
[b] Expressed as aerodynamic equivalent diameter.
[c] A = coal ash weight, as fired.
[d] Estimated control efficiency for multiple cyclone, 80%; baghouse, 99.8%.
[e] Insufficient data.

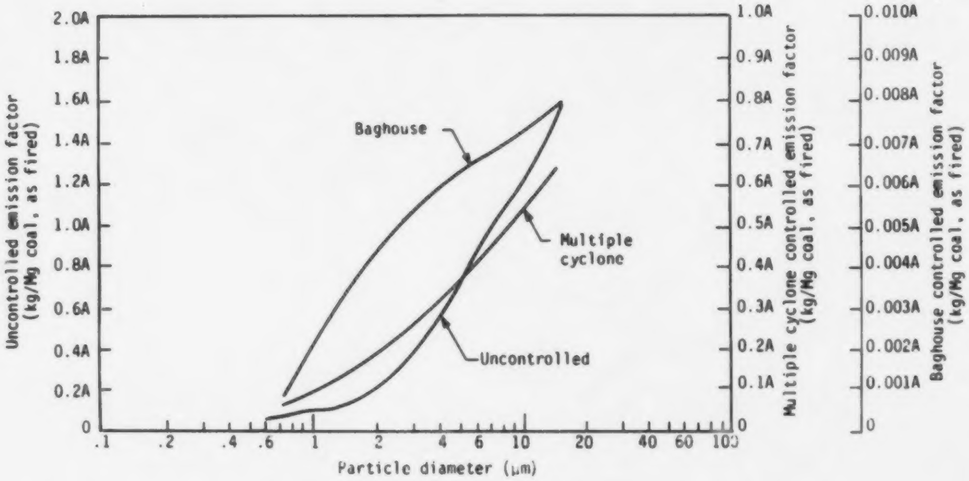

Figure 1.2-1. Cumulative size specific emission factors for dry bottom boilers burning pulverized anthracite coal.

TABLE 1.2-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR TRAVELING GRATE STOKERS BURNING ANTHRACITE COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factor [kg/Mg (lb/ton) coal, as fired]
	Uncontrolled[c]	Controlled
15	64	2.9 (5.8)
10	52	2.4 (4.8)
6	42	1.9 (3.8)
2.5	27	1.2 (2.4)
1.25	24	1.1 (2.2)
1.00	23	1.1 (2.2)
0.625	d	d
TOTAL	100	4.6 (9.2)

[a] Reference 19.

[b] Expressed as aerodynamic equivalent diameter.

[c] May also be used for uncontrolled hand fired units.

[d] Insufficient data.

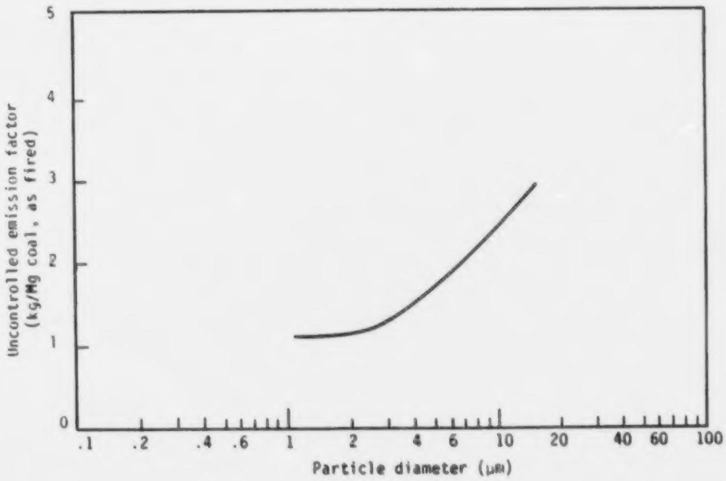

Figure 1.2-2. Cumulative size specific emission factors for traveling grate stokers burning anthracite coal.

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1.3 FUEL OIL COMBUSTION

1.3.1 General[1-2,22]

Fuel oils are broadly classified into two major types, distillate and residual. Distillate oils (fuel oil grade Nos. 1 and 2) are used mainly in domestic and small commercial applications in which easy fuel burning is required. Distillates are more volatile and less viscous that residual oils, having negligible ash and nitrogen contents and usually containing less than 0.3 weight percent sulfur. Residual oils (grade Nos. 4, 5 and 6), on the other hand, are used mainly in utility, industrial and large commercial applications with sophisticated combustion equipment. No. 4 oil is sometimes classified as a distillate, and No. 6 is sometimes referred to as Bunker C. Being more viscous and less volatile than distillate oils, the heavier residual oils (Nos. 5 and 6) must be heated to facilitate handling and proper atomization. Because residual oils are produced from the residue after lighter fractions (gasoline, kerosene and distillate oils) have been removed from the crude oil, they contain significant quantities of ash, nitrogen and sulfur. Properties of typical fuel oils can be found in Appendix A.

1.3.2 Emissions

Emissions from fuel oil combustion depend on the grade and composition of the fuel, the type and size of the boiler, the firing and loading practices used, and the level of equipment maintenance. Table 1.3-1 presents emission factors for fuel oil combustion pollutants, and Tables 1.3-2 through 1.3-5 present cumulative size distribution data and size specific emission factors for particulate emissions from fuel oil combustion. Uncontrolled and controlled size specific emission factors are presented in Figures 1.3-1 through 1.3-4. Distillate and residual oil categories are given separately, because their combustion produces significantly different particulate, SO_2 and NO_x emissions.

Particulate Matter[3-7,12-13,24,26-27] - Particulate emissions depend most on the grade of fuel fired. The lighter distillate oils result in particulate formation significantly lower than with heavier residual oils. Among residual oils, Nos. 4 and 5 usually produce less particulate than does the heavier No. 6.

In boilers firing No. 6, particulate emissions can be described, on the average, as a function of the sulfur content of the oil. As shown in Table 1.3-1), particulate emissions can be reduced considerably when low sulfur No. 6 oil is fired. This is because low sulfur No. 6, either refined from naturally low sulfur crude oil or desulfurized by one of several current processes, exhibits substantially lower viscosity and reduced asphaltene, ash and sulfur, which results in better atomization and cleaner combustion.

Boiler load can also affect particulate emissions in units firing No. 6 oil. At low load conditions, particulate emissions may be lowered 30 to 40 percent from utility boilers and by as much as 60 percent from small industrial and commercial units. No significant particulate reductions have been noted at

TABLE 1.3-1. UNCONTROLLED EMISSION FACTORS FOR FUEL OIL COMBUSTION

EMISSION FACTOR RATING: A

Boiler Type[a]	Particulate Matter[b]		Sulfur Dioxide[c]		Sulfur Trioxide		Carbon Monoxide[d]		Nitrogen Oxide[e]		Volatile Organics[f]			
											Nonmethane		Methane	
	kg/10^3l	lb/10^3gal	kg/10^3l	lb/10^3gal	kg/10^3l	lb/10^3gal	kg/10^3l	lb/10^3gal	kg/10^3l	lb/10^3gal	kg/10^3l	lb/10^3gal	kg/10^3l	lb/10^3gal
Utility Boilers														
Residual Oil	[g]	[g]	19S	157S	0.34S[h]	2.9S[h]	0.6	5	8.0 (12.6)(5)[i]	67 (105)(42)[i]	0.09	0.76	0.03	0.28
Industrial Boilers														
Residual Oil	[g]	[g]	19S	157S	0.24S	2S	0.6	5	6.6[j]	55[j]	0.034	0.28	0.12	1.0
Distillate Oil	0.24	2	17S	142S	0.24S	2S	0.6	5	2.4	20	0.024	0.2	0.006	0.052
Commercial Boilers														
Residual Oil	[g]	[g]	19S	157S	0.24S	2S	0.6	5	6.6	55	0.14	1.13	0.057	0.475
Distillate Oil	0.24	2	17S	142S	0.24S	2S	0.6	5	2.4	20	0.04	0.34	0.026	0.216
Residential Furnaces														
Distillate Oil	0.3	2.5	17S	142S	0.24S	2S	0.6	5	2.2	18	0.085	0.713	0.214	1.78

[a] Boilers can be approximately classified according to their gross (higher) heat rate as shown below:
Utility (power plant) boilers: >106 × 10^9 J/hr (>100 × 10^6 Btu/hr)
Industrial boilers: 10.6 × 10^9 to 106 × 10^9 J/hr (10 × 10^6 to 100 × 10^6 Btu/hr)
Commercial boilers: 0.5 × 10^9 to 10.6 × 10^9 J/hr (0.5 × 10^6 to 10 × 10^6 Btu/hr)
Residential furnaces: <0.5 × 10^9 J/hr (<0.5 × 10^6 Btu/hr)

[b] References 3-7 and 24-25. Particulate matter is defined in this section as that material collected by EPA Method 5 (front half catch).

[c] References 1-5. S indicates that the weight % of sulfur in the oil should be multiplied by the value given.

[d] References 3-5 and 8-10. Carbon monoxide emissions may increase by factors of 10 to 100 if the unit is improperly operated or not well maintained.

[e] Expressed as NO_2. References 1-5, 8-11, 17 and 26. Test results indicate that at least 95% by weight of NO_x is NO for all boiler types except residential furnaces, where about 75% is NO.

[f] References 18-21. Volatile organic compound emissions are generally negligible unless boiler is improperly operated or not well maintained, in which case emissions may increase by several orders of magnitude.

[g] Particulate emission factors for residual oil combustion are, on average, a function of fuel oil grade and sulfur content:
Grade 6 oil: $1.25(S) + 0.38$ kg/10^3 liter [$10(S) + 3$ lb/10^3 gal] where S is the weight % of sulfur in the oil. This relationship is based on 81 individual tests and has a correlation coefficient of 0.65.
Grade 5 oil: 1.25 kg/10^3 liter (10 lb/10^3 gal)
Grade 4 oil: 0.88 kg/10^3 liter (7 lb/10^3 gal)

[h] Reference 25.

[i] Use 5 kg/10^3 liters (42 lb/10^3 gal) for tangentially fired boilers, 12.6 kg/10^3 liters (105 lb/10^3gal) for vertical fired boilers, and 8.0 kg/10^3 liters (67 lb/10^3 gal) for all others, at full load and normal (>15%) excess air. Several combustion modifications can be employed for NO_x reduction: (1) limited excess air can reduce NO_x emissions 5-20%, (2) staged combustion 20-40%, (3) using low NO_x burners 20-50%, and (4) ammonia injection can reduce NO_x emissions 40-70% but may increase emissions of ammonia. Combinations of these modifications have been employed for further reductions in certain boilers. See Reference 23 for a discussion of these and other NO_x reducing techniques and their operational and environmental impacts.

[j] Nitrogen oxides emissions from residual oil combustion in industrial and commercial boilers are strongly related to fuel nitrogen content, estimated more accurately by the empirical relationship:
kg $NO_2/10^3$ liters $= 2.75 + 50(N)^2$ [lb $NO_2/10^3$gal $= 22 + 400(N)^2$] where N is the weight % of nitrogen in the oil. For residual oils having high (>0.5 weight %) nitrogen content, use 15 kg $NO_2/10^3$ liter (120 lb $NO_2/10^3$gal) as an emission factor.

low loads from boilers firing any of the lighter grades, however. At too low a load condition, proper combustion conditions cannot be maintained, and particulate emissions may increase drastically. It should be noted, in this regard, that any condition that prevents proper boiler operation can result in excessive particulate formation.

Sulfur Oxides [1-5,25,27] - Total SO_x emissions are almost entirely dependent on the sulfur content of the fuel and are not affected by boiler size, burner design, or grade of fuel being fired. On the average, more than 95 percent of the fuel sulfur is emitted as SO_2, about 1 to 5 percent as SO_3 and about 1 to 3 percent as sulfate particulate. SO_3 readily reacts with water vapor (in both air and flue gases) to form a sulfuric acid mist.

Nitrogen Oxides [1-11,4,17,23,27] - Two mechanisms form NO_x, oxidation of fuelbound nitrogen and thermal fixation of the nitrogen in combustion air. Fuel NO_x is primarily a function of the nitrogen content of the fuel and the available oxygen. On average, about 45 percent of the fuel nitrogen is converted to NO_x, but this may vary from 20 to 70 percent. Thermal NO_x, rather, is largely a function of peak flame temperature and available oxygen, factors which depend on boiler size, firing configuration and operating practices.

Fuel nitrogen conversion is the more important NO_x forming mechanism in residual oil boilers. Except in certain large units having unusually high peak flame temperatures, or in units firing a low nitrogen residual oil, fuel NO_x will generally account for over 50 percent of the total NO_x generated. Thermal fixation, on the other hand, is the dominant NO_x forming mechanism in units firing distillate oils, primarily because of the negligible nitrogen content in these lighter oils. Because distillate oil fired boilers usually have low heat release rates, however, the quantity of thermal NO_x formed in them is less than that of larger units.

A number of variables influence how much NO_x is formed by these two mechanisms. One important variable is firing configuration. Nitrogen oxide emissions from tangentially (corner) fired boilers are, on the average, less than those of horizontally opposed units. Also important are the firing practices employed during boiler operation. Limited excess air firing, flue gas recirculation, staged combustion, or some combination thereof may result in NO_x reductions of 5 to 60 percent. See Section 1.4 for a discussion of these techniques. Load reduction can likewise decrease NO_x production. Nitrogen oxide emissions may be reduced from 0.5 to 1 percent for each percentage reduction in load from full load operation. It should be noted that most of these variables, with the exception of excess air, infuence the NO_x emissions only of large oil fired boilers. Limited excess air firing is possible in many small boilers, but the resulting NO_x reductions are not nearly so significant.

Other Pollutants[18-21] - As a rule, only minor amounts of volatile organic compounds (VOC) and carbon monoxide will be emitted from the combustion of fuel oil. The rate at which VOCs are emitted depends on combustion efficiency. Emissions of trace elements from oil fired boilers are relative to the trace element concentrations of the oil.

TABLE 1.3-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UTILITY BOILERS FIRING RESIDUAL OIL[a]

EMISSION FACTOR RATING: C (uncontrolled)
E (ESP controlled)
D (scrubber controlled)

Particle size[b] (um)	Cumulative mass % $\leq$ stated size			Cumulative emission factor[c] [kg/10^3 l (lb/10^3 gal)]		
	Uncontrolled	Controlled		Uncontrolled	Controlled[d]	
		ESP	Scrubber		ESP	Scrubber
15	80	75	100	0.80A (6.7A)	0.0060A (0.05A)	0.06A (0.50A)
10	71	63	100	0.71A (5.9A)	0.0050A (0.042A)	0.06A (0.50A)
6	58	52	100	0.58A (4.8A)	0.0042A (0.035A)	0.06A (0.50A)
2.5	52	41	97	0.52A (4.3A)	0.0033A (0.028A)	0.058A (0.48A)
1.25	43	31	91	0.43A (3.6A)	0.0025A (0.021A)	0.055A (0.46A)
1.00	39	28	84	0.39A (3.3A)	0.0022A (0.018A)	0.050A (0.42A)
0.625	20	10	64	0.20A (1.7A)	0.0008A (0.007A)	0.038A (0.32A)
TOTAL	100	100	100	1A (8.3A)	0.008A (0.067A)	0.06A (0.50A)

[a] Reference 29. ESP = electrostatic precipitator.
[b] Expressed as aerodynamic equivalent diameter.
[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:
Grade 6 Oil: $A = 1.25(S) + 0.38$
Where S is the weight % of sulfur in the oil
Grade 5 Oil: $A = 1.25$
Grade 4 Oil: $A = 0.88$
[d] Estimated control efficiency for scrubber, 94%; ESP, 99.2%.

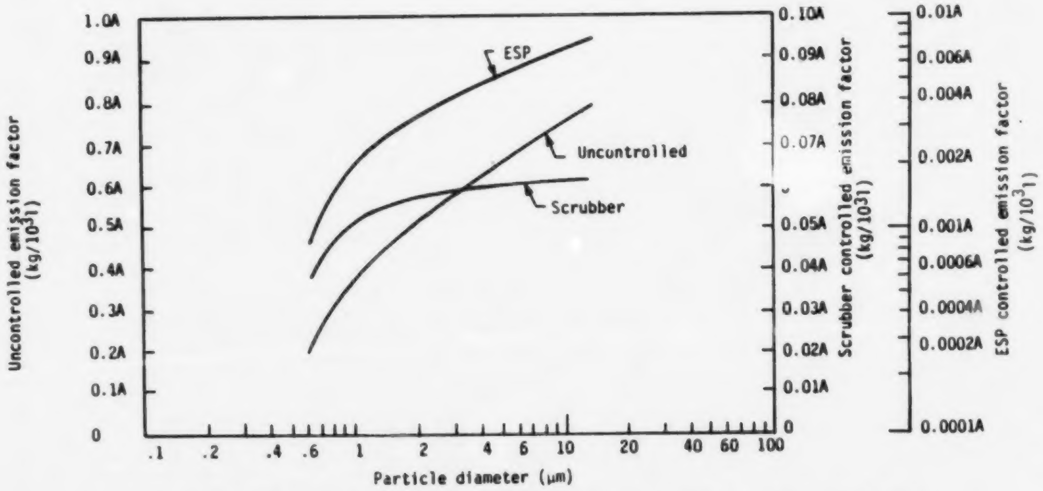

Figure 1.3-1. Cumulative size specific emission factors for utility boilers firing residual oil.

TABLE 1.3-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR INDUSTRIAL BOILERS FIRING RESIDUAL OIL[a]

EMISSION FACTOR RATING: D (uncontrolled)
E (multiple cyclone controlled)

Particle size[b] (um)	Cumulative mass % ≤ stated size		Cumulative emission factor[c] kg/10^3 l (lb/10^3 gal)	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[e]
15	91	100	0.91A (7.59A)	0.20A (1.67A)
10	86	95	0.86A (7.17A)	0.19A (1.58A)
6	77	72	0.77A (6.42A)	0.14A (1.17A)
2.5	56	22	0.56A (4.67A)	0.04A (0.33A)
1.25	39	21	0.39A (3.25A)	0.04A (0.33A)
1.00	36	21	0.36A (3.00A)	0.04A (0.33A)
0.625	30	d	0.30A (2.50A)	d
TOTAL	100	100	1A (8.34A)	0.2A (1.67A)

[a] Reference 29.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:

Grade 6 Oil: $A = 1.25(S) + 0.38$
Where S is the weight % of sulfur in the oil
Grade 5 Oil: $A = 1.25$
Grade 4 Oil: $A = 0.88$

[d] Insufficient data.

[e] Estimated control efficiency for multiple cyclone, 80%.

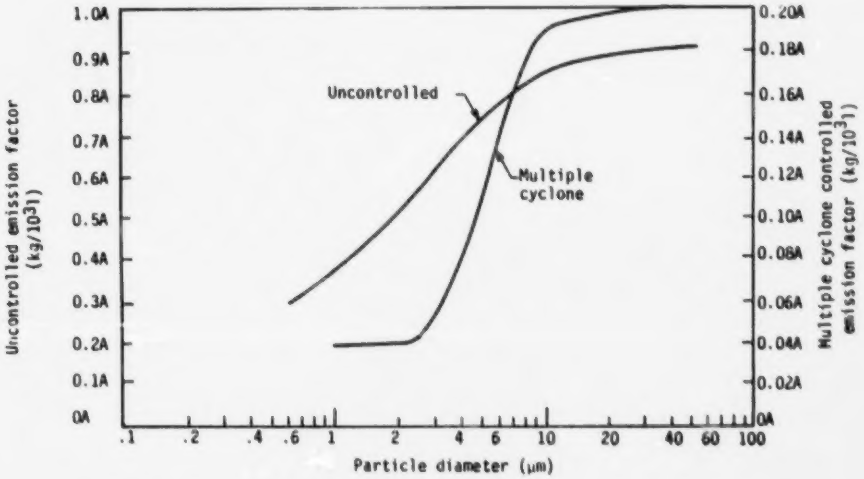

Figure 1.3-2. Cumulative size specific emission factors for industrial boilers firing residual oil.

TABLE 1.3-4. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNCONTROLLED INDUSTRIAL BOILERS FIRING DISTILLATE OIL[a]

EMISSION FACTOR RATING: E

Particle size[b] (um)	Cumulative mass % ≤ stated size	Cumulative emission factor kg/10^3 l (lb/10^3 gal)
	Uncontrolled	Uncontrolled
15	68	0.16 (1.33)
10	50	0.12 (1.00)
6	30	0.07 (0.58)
2.5	12	0.03 (0.25)
1.25	9	0.02 (0.17)
1.00	8	0.02 (0.17)
0.625	2	0.005 (0.04)
TOTAL	100	0.24 (2.00)

[a] Reference 29.

[b] Expressed as aerodynamic equivalent diameter.

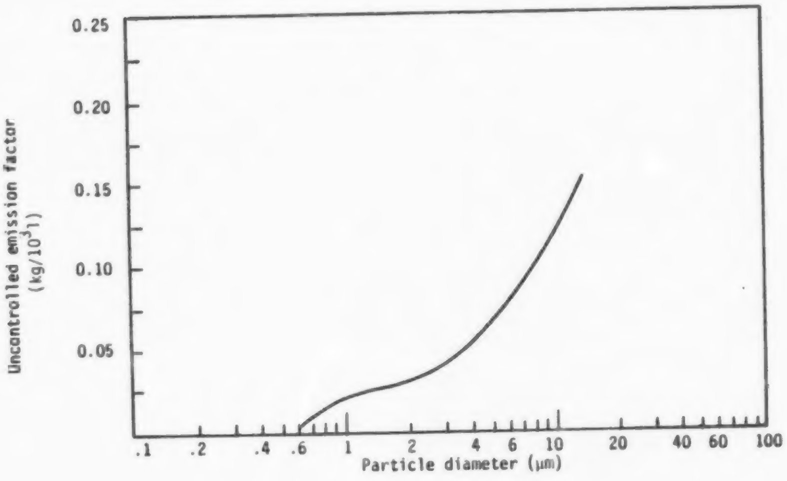

Figure 1.3-3. Cumulative size specific emission factors for uncontrolled industrial boilers firing distillate oil.

TABLE 1.3-5. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR UNCONTROLLED COMMERCIAL BOILERS BURNING RESIDUAL AND DISTILLATE OIL[a]

EMISSION FACTOR RATING: D

Particle size[b] (um)	Cumulative mass % $\leq$ stated size		Cumulative emission factor kg/10^3 l (lb/10^3 gal)	
	Uncontrolled with residual oil	Uncontrolled with distillate oil[c]	Uncontrolled with residual oil	Uncontrolled with distillate oil
15	78	60	0.78A (6.50A)	0.14 (1.17)
10	62	55	0.62A (5.17A)	0.13 (1.08)
6	44	49	0.44A (3.67A)	0.12 (1.00)
2.5	23	42	0.23A (1.92A)	0.10 (0.83)
1.25	16	38	0.16A (1.33A)	0.09 (0.75)
1.00	14	37	0.14A (1.17A)	0.09 (0.75)
0.625	13	35	0.13A (1.08A)	0.08 (0.67)
TOTAL	100	100	1A (8.34A)	0.24 (2.00)

[a] Reference 29.

[b] Expressed as aerodynamic equivalent diameter.

[c] Particulate emission factors for residual oil combustion without emission controls are, on average, a function of fuel oil grade and sulfur content:

Grade 6 Oil: A = 1.25 (S) + 0.38
Where S is the weight % of sulfur in the oil
Grade 5 Oil: A = 1.25
Grade 4 Oil: A = 0.88

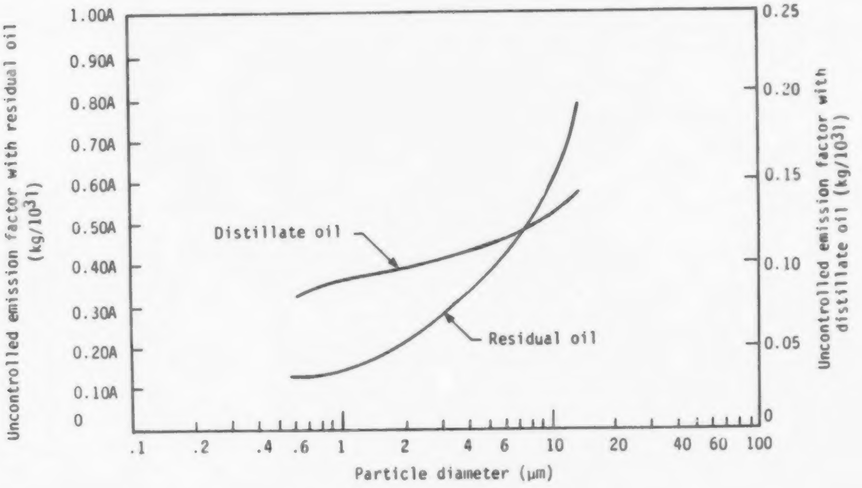

Figure 1.3-4. Cumulative size specific emission factors for uncontrolled commercial boilers burning residual and distillate oil.

Organic compounds present in the flue gas streams of boilers include aliphatic and aromatic hydrocarbons, esters, ethers, alcohols, carbonyls, carboxylic acids and polycylic organic matter. The last includes all organic matter having two or more benzene rings.

Trace elements are also emitted from the combustion of fuel oil. The quantity of trace elements emitted depends on combustion temperature, fuel feed mechanism and the composition of the fuel. The temperature determines the degree of volatilization of specific compounds contained in the fuel. The fuel feed mechanism affects the separation of emissions into bottom ash and fly ash.

If a boiler unit is operated improperly or is poorly maintained, the concentrations of carbon monoxide and VOCs may increase by several orders of magnitude.

1.3.3 Controls

The various control devices and/or techniques employed on oil fired boilers depend on the type of boiler and the pollutant being controlled. All such controls may be classified into three categories, boiler modification, fuel substitution and flue gas cleaning.

Boiler Modification[1-4,8-9,13-14,23]- Boiler modification includes any physical change in the boiler apparatus itself or in its operation. Maintenance of the burner system, for example, is important to assure proper atomization and subsequent minimization of any unburned combustibles. Periodic tuning is important in small units for maximum operating efficiency and emission control, particularly of smoke and CO. Combustion modifications, such as limited excess air firing, flue gas recirculation, staged combustion and reduced load operation, result in lowered NO_x emissions in large facilities. See Table 1.3-1 for specific reductions possible through these combustion modifications.

Fuel Substitution[3,5,12,28]- Fuel substitution, the firing of "cleaner" fuel oils, can substantially reduce emissions of a number of pollutants. Lower sulfur oils, for instance, will reduce SO_x emissions in all boilers, regardless of size or type of unit or grade of oil fired. Particulates generally will be reduced when a lighter grade of oil is fired. Nitrogen oxide emissions will be reduced by switching to either a distillate oil or a residual oil with less nitrogen. The practice of fuel substitution, however, may be limited by the ability of a given operation to fire a better grade of oil and by the cost and availability thereof.

Flue Gas Cleaning[15-16,28] - Flue gas cleaning equipment generally is employed only on large oil fired boilers. Mechanical collectors, a prevalent type of control device, are primarily useful in controlling particulates generated during soot blowing, during upset conditions, or when a very dirty heavy oil is fired. During these situations, high efficiency cyclonic collectors can effect up to 85 percent control of particulate. Under normal firing conditions, or when a clean oil is combusted, cyclonic collectors will not be nearly so effective because of the high percentage of small particles (less than 3 micrometers diameter) emitted.

Electrostatic precipitators are commonly used in oil fired power plants. Older precipitators, usually small, remove generally 40 to 60 percent of the particulate matter. Because of the low ash content of the oil, greater collection efficiency may not be required. Today, new or rebuilt electrostatic precipitators have collection efficiencies of up to 90 percent.

Scrubbing systems have been installed on oil fired boilers, especially of late, to control both sulfur oxides and particulate. These systems can achieve SO_2 removal efficiencies of 90 to 95 percent and particulate control efficiencies of 50 to 60 percent.

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1.4 NATURAL GAS COMBUSTION

1.4.1 General[1-2]

Natural gas is one of the major fuels used throughout the country. It is used mainly for power generation, for industrial process steam and heat production, and for domestic and commercial space heating. The primary component of natural gas is methane, although varying amounts of ethane and smaller amounts of nitrogen, helium and carbon dioxide are also present. Gas processing plants are required for recovery of liquefiable constitutents and removal of hydrogen sulfide (H_2S) before the gas is used (see Natural Gas Processing, Section 9.2). The average gross heating value of natural gas is approximately 9350 kilocalories per standard cubic meter (1050 British thermal units/standard cubic foot), usually varying from 8900 to 9800 kcal/scm (1000 to 1100 Btu/scf).

1.4.2 Emission And Controls[3-26]

Even though natural gas is considered to be a relatively clean fuel, some emissions can occur from the combustion reaction. For example, improper operating conditions, including poor mixing, insufficient air, etc., may cause large amounts of smoke, carbon monoxide and hydrocarbons. Moreover, because a sulfur containing mercaptan is added to natural gas to permit detection, small amounts of sulfur oxides will also be produced in the combustion process.

Nitrogen oxides are the major pollutants of concern when burning natural gas. Nitrogen oxide emissions are functions of combustion chamber temperature and combustion product cooling rate. Emission levels vary considerably with the type and size of unit and with operating conditions.

In some large boilers, several operating modifications may be used for NO_x control. Staged combustion, for example, including off-stoichiometric firing and/or two stage combustion, can reduce emissions by 5 to 50 percent.[26] In off-stoichiometric firing, also called "biased firing", some burners are operated fuel rich, some fuel lean, and others may supply air only. In two stage combustion, the burners are operated fuel rich (by introducing only 70 to 90 percent stoichiometric air), with combustion being completed by air injected above the flame zone through second stage "NO ports". In staged combustion, NO_x emissions are reduced because the bulk of combustion occurs under fuel rich conditions.

Other NO_x reducing modifications include low excess air firing and flue gas recirculation. In low excess air firing, excess air levels are kept as low as possible without producing unacceptable levels of unburned combustibles (carbon monoxide, volatile organic compounds and smoke) and/or other operating problems. This technique can reduce NO_x emissions 5 to 35 percent, primarily because of lack of oxygen during combustion. Flue gas recirculation into the primary combustion zone, because the flue gas is relatively cool and oxygen deficient, can also lower NO_x emissions 4 to 85 percent, depending on the amount of gas recirculated. Flue gas recirculation is best suited for new boilers. Retrofit application would require extensive burner modifications.

TABLE 1.4-1. UNCONTROLLED EMISSION FACTORS FOR NATURAL GAS COMBUSTION[a]

Furnace size & type (10^6 Btu/hr heat input)	Particulate[b]		Sulfur dioxide[c]		Nitrogen oxides[d]		Carbon monoxide[e]		Volatile organics			
									Nonmethane		Methane	
	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$	$kg/10^6 m^3$	$lb/10^6 ft^3$
Utility boilers (> 100)	16 - 80	1 - 5	9.6	0.6	8800[h]	550[h]	640	40	23	1.4	4.8	0.3
Industrial boilers (10 - 100)	16 - 80	1 - 5	9.6	0.6	2240	140	560	35	44	2.8	48	3
Domestic and commercial boilers (< 10)	16 - 80	1 - 5	9.6	0.6	1600	100	320	20	84	5.3	43	2.7

[a] Expressed as weight/volume fuel fired.

[b] References 15-18.

[c] Reference 4. Based on avg. sulfur content of natural gas, 4600 $g/10^6 Nm^3$ (2000 $gr/10^6$ scf).

[d] References 4-5, 7-8, 11, 14, 18-19, 21.

[e] Expressed as NO_2. Tests indicate about 95 weight % NO_x is NO_2.

[f] References 4, 7-8, 16, 18, 22-25.

[g] References 16, 18. May increase 10 - 100 times with improper operation or maintenance.

[h] For tangentially fired units, use 4400 $kg/10^6 m^3$ (275 $lb/10^6 ft^3$). At reduced loads, multiply factor by load reduction coefficient in Figure 1.4-1. For potential NO_x reductions by combustion modification, see text. Note that NO_x reduction from these modifications will also occur at reduced load conditions.

Studies indicate that low NO_x burners (20 to 50 percent reduction) and ammonia injection (40 to 70 percent reduction) also offer NO_x emission reductions.

Combinations of the above combustion modifications may also be employed to reduce NO_x emissions further. In some boilers, for instance, NO_x reductions as high as 70 to 90 percent have been produced by employing several of these techiques simultaneously. In general, however, because the net effect of any of these combinations varies greatly, it is difficult to predict what the reductions will be in individual applications.

Although not measured, all particulate has been estimated to be less than 1 micrometer in size.[27] Emission factors for natural gas combustion are presented in Table 1.4-1, and factor ratings in Table 1.4-2.

TABLE 1.4-2. FACTOR RATINGS FOR NATURAL GAS COMBUSTION

Furnace type	Particulate	Sulfur oxides	Nitrogen oxides	Carbon monoxide	Volatile organics	
					Nonmethane	Methane
Utility boiler	B	A	A	A	C	C
Industrial boiler	B	A	A	A	C	C
Commercial boiler	B	A	A	A	D	D
Residential furnace	B	A	A	A	D	D

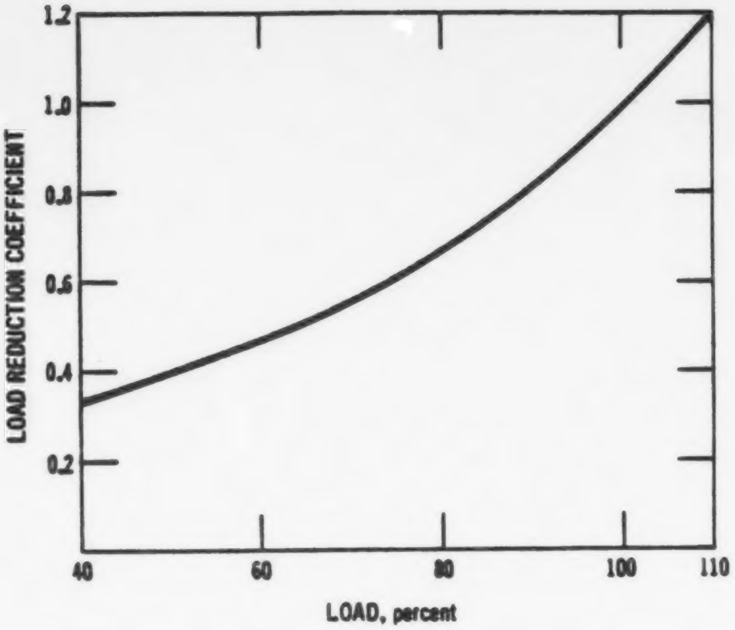

Figure 1.4-1. Load reduction coefficient as function of boiler load. (Used to determine NO_x reductions at reduced loads in large boilers.)

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1.6 WOOD WASTE COMBUSTION IN BOILERS

1.6.1 General[1-3]

The burning of wood waste in boilers is mostly confined to those industries where it is available as a byproduct. It is burned both to obtain heat energy and to alleviate possible solid waste disposal problems. Wood waste may include large pieces like slabs, logs and bark strips, as well as cuttings, shavings, pellets and sawdust, and heating values for this waste range from about 4,400 to 5,000 kilocalories per kilogram of fuel dry weight (7,940 to 9,131 Btu/lb). However, because of typical moisture contents of 40 to 75 percent, the heating values for many wood waste materials as actually fired are as low as 2,200 to 3,300 kilocalories per kilogram of fuel. Generally, bark is the major type of waste burned in pulp mills, and either a varying mixture of wood and bark waste or wood waste alone are most frequently burned in the lumber, furniture and plywood industries.

1.6.2 Firing Practices[1-3]

Varied boiler firing configurations are used in burning wood waste. One common type in smaller operations is the dutch oven, or extension type of furnace with a flat grate. This unit is widely used because it can burn fuels with very high moisture. Fuel is fed into the oven through apertures atop a firebox and is fired in a cone shaped pile on a flat grate. The burning is done in two stages, drying and gasification, and combustion of gaseous products. The first stage takes place in a cell separated from the boiler section by a bridge wall. The combustion stage takes place in the main boiler section. The dutch oven is not responsive to changes in steam load, and it provides poor combustion control.

In another type, the fuel cell oven, fuel is dropped onto suspended fixed grates and is fired in a pile. Unlike the dutch oven, the fuel cell also uses combustion air preheating and repositioning of the secondary and tertiary air injection ports to improve boiler efficiency.

In many large operations, more conventional boilers have been modified to burn wood waste. These units may include spreader stokers with traveling grates, vibrating grate stokers, etc., as well as tangentially fired or cyclone fired boilers. The most widely used of these configurations is the spreader stoker. Fuel is dropped in front of an air jet which casts the fuel out over a moving grate, spreading it in an even thin blanket. The burning is done in three stages in a single chamber, (1) drying, (2) distillation and burning of volatile matter and (3) burning of carbon. This type of operation has a fast response to load changes, has improved combustion control and can be operated with multiple fuels. Natural gas or oil are often fired in spreader stoker boilers as auxiliary fuel. This is done to maintain constant steam when the wood waste supply fluctuates and/or to provide more steam than is possible from the waste supply alone.

TABLE 1.6-1. EMISSION FACTORS FOR WOOD AND BARK COMBUSTION IN BOILERS

Pollutant/Fuel type	kg/Mg	lb/ton	Emission Factor Rating
Particulate[a]			
Bark[b]			
Multiclone, with flyash reinjection[c]	7	14	B
Multiclone, without flyash reinjection[c]	4.5	9	B
Uncontrolled	24	47	B
Wood/bark mixture[d]			
Multiclone, with flyash reinjection[c,e]	3	6	C
Multiclone, without flyash reinjection[c,e]	2.7	5.3	C
Uncontrolled[f]	3.6	7.2	C
Wood[g]			
Uncontrolled	4.4	8.8	C
Sulfur dioxide[h]	0.075 (0.01 - 0.2)	0.15 (0.02 - 0.4)	B
Nitrogen oxides (as NO_2)[j]			
50,000 - 400,000 lb steam/hr	1.4	2.8	B
<50,000 lb steam/hr	0.34	0.68	B
Carbon monoxide[k]	2 - 24	4 - 47	C
VOC			
Nonmethane[m]	0.7	1.4	D
Methane[n]	0.15	0.3	E

[a] References 2, 4, 9, 17-18, 20. With gas or oil as auxiliary fuel, all particulate assumed to result from only wood waste fuel. May include condensible hydrocarbons of pitches and tars, mostly from back half catch of EPA Method 5. Tests indicate condensible hydrocarbons about 4% of total particulate weight.

[b] Based on fuel moisture content about 50%.

[c] References 4,7-8. After control equipment, assuming an average collection efficiency of 80%. Data indicate that 50% flyash reinjection increases dust load at cyclone inlet 1.2 to 1.5 times, and 100% flyash reinjection increases the load 1.5 to 2 times.

[d] Based on fuel moisture content of 33%.

[e] Based on large dutch ovens and spreader stokers (avg. 23,430 kg steam/hr) with steam pressures 20 - 75 kpa (140 - 530 psi).

[f] Based on small dutch ovens and spreader stokers (usually $\leq$9075 kg steam/hr), with steam pressures 5 - 30 kpa (35 - 230 psi). Careful air adjustments and improved fuel separation and firing sometimes used, but effects can not be isolated.

[g] References 12-13, 19, 27. Wood waste includes cuttings, shavings, sawdust and chips, but not bark. Moisture content ranges 3 - 50 weight %. Based on small units ($\leq$3000 kg steam/hr).

[h] Reference 23. Based on dry weight of fuel. From tests of fuel sulfur content and SO_2 emissions at 4 mills burning bark. Lower limit of range (in parentheses) should be used for wood, and higher values for bark. Heating value of 5000 kcal/kg (9000 Btu/lb) is assumed.

[j] References 7, 24-26. Several factors can influence emission rates, including combustion zone, temperature, excess air, boiler operating conditions, fuel moisture and fuel nitrogen content.

[k] Reference 30.

[m] References 20, 30. Nonmethane VOC reportedly consists of compounds with high vapor pressure, such as alpha pinene.

[n] Reference 30. Based on approximation of methane/nonmethane ratio, quite variable. Methane, expressed as % total VOC, varied 0 - 74 weight %.

Sander dust is often burned in various boiler types at plywood, particle board and furniture plants. Sander dust contains fine wood particles with low moisture content (less than 20 weight percent). It is fired in a flaming horizontal torch, usually with natural gas as an ignition aid or supplementary fuel.

1.6.3 Emissions And Controls[4-28]

The major emission of concern from wood boilers is particulate matter, although other pollutants, particularly carbon monoxide, may be emitted in significant amounts under poor operating conditions. These emissions depend on a number of variables, including (1) the composition of the waste fuel burned, (2) the degree of flyash reinjection employed and (3) furnace design and operating conditions.

The composition of wood waste depends largely on the industry whence it originates. Pulping operations, for example, produce great quantities of bark that may contain more than 70 weight percent moisture and sand and other noncombustibles. Because of this, bark boilers in pulp mills may emit considerable amounts of particulate matter to the atmosphere unless they are well controlled. On the other hand, some operations, such as furniture manufacturing, produce a clean dry wood waste, 5 to 50 weight percent moisture, with relatively little particulate emission when properly burned. Still other operations, such as sawmills, burn a varying mixture of bark and wood waste that results in particulate emissions somewhere between these two extremes.

Furnace design and operating conditions are particularly important when firing wood waste. For example, because of the high moisture content that can be present in this waste, a larger than usual area of refractory surface is often necessary to dry the fuel before combustion. In addition, sufficient secondary air must be supplied over the fuel bed to burn the volatiles that account for most of the combustible material in the waste. When proper drying conditions do not exist, or when secondary combustion is incomplete, the combustion temperature is lowered, and increased particulate, carbon monoxide and hydrocarbon emissions may result. Lowering of combustion temperature generally means decreased nitrogen oxide emissions. Also, short term emissions can fluctuate with significant variations in fuel moisture content.

Flyash reinjection, which is common to many larger boilers to improve fuel efficiency, has a considerable effect on particulate emissions. Because a fraction of the collected flyash is reinjected into the boiler, the dust loading from the furnace, and consequently from the collection device, increases significantly per unit of wood waste burned. It is reported that full reinjection can cause a tenfold increase in the dust loadings of some systems, although increase of 1.2 to 2 times are more typical for boilers using 50 to 100 percent reinjection. A major factor affecting this dust loading increase is the extent to which the sand and other noncombustibles can be separated from the flyash before reinjection to the furnace.

Although reinjection increases boiler efficiency from 1 to 4 percent and reduces emissions of uncombusted carbon, it increases boiler maintenance requirements, decreases average flyash particle size and makes collection more difficult. Properly designed reinjection systems should separate sand and char

TABLE 1.6-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR BARK FIRED BOILERS[a]

EMISSION FACTOR RATING: D

Particle size[b] (μm)	Cumulative mass % ≤ stated size				Cumulative emission factor [kg/Mg (lb/ton) bark, as fired]			
	Uncontrolled	Controlled			Uncontrolled	Controlled		
		Multiple cyclone[c]	Multiple cyclone[d]	Scrubber[e]		Multiple cyclone[c]	Multiple cyclone[d]	Scrubber[e]
15	42	90	40	92	10.1 (20.2)	6.3 (12.6)	1.8 (3.6)	1.32 (2.64)
10	35	79	36	87	8.4 (16.8)	5.5 (11.0)	1.62 (3.24)	1.25 (2.50)
6	28	64	30	78	6.7 (13.4)	4.5 (9.0)	1.35 (2.7)	1.12 (2.24)
2.5	21	40	19	56	5.0 (10.0)	2.8 (5.6)	0.86 (1.72)	0.81 (1.62)
1.25	15	26	14	29	3.6 (7.2)	1.8 (3.6)	0.63 (1.26)	0.42 (0.84)
1.00	13	21	11	23	3.1 (6.2)	1.5 (3.0)	0.5 (1.0)	0.33 (0.66)
0.625	9	15	8	14	2.2 (4.4)	1.1 (2.2)	0.36 (0.72)	0.20 (0.40)
TOTAL	100	100	100	100	24 (48)	7 (14)	4.5 (9.0)	1.44 (2.88)

[a] Reference 31. All spreader stoker boilers.

[b] Expressed as aerodynamic equivalent diameter.

[c] With flyash reinjection.

[d] Without flyash reinjection.

[e] Estimated control efficiency for scrubber, 94%.

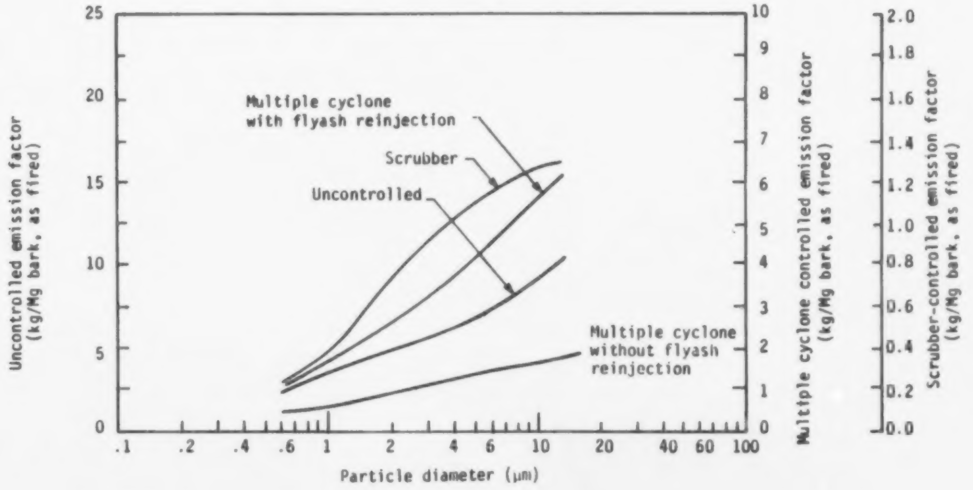

Figure 1.6-1. Cumulative size specific emission factors for bark fired boilers.

from the exhaust gases, to reinject the larger carbon particles to the furnace and to divert the fine sand particles to the ash disposal system.

Several factors can influence emissions, such as boiler size and type, design features, age, load factors, wood species and operating procedures. In addition, wood is often cofired with other fuels. The effect of these factors on emissions is difficult to quantify. It is best to refer to the references for further information.

The use of multitube cyclone mechanical collectors provides particulate control for many hogged boilers. Usually, two multicyclones are used in series, allowing the first collector to remove the bulk of the dust and the second to remove smaller particles. The efficiency of this arrangement is from 65 to 95 percent. Low pressure drop scrubbers and fabric filters have been used extensively for many years, and pulse jets have been used in the western U. S.

Emission factors and emission factor ratings for wood waste boilers are presented in Table 1.6-1, except for cumulative size distribution data, size specific emission factors for particulate, and emission factor ratings for the cumulative particle size distribution, all presented in Tables 1.6-2 through 1.6-3. Uncontrolled and controlled size specific emission factors are in Figures 1.6-1 and 1.6-2.

TABLE 1.6-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR WOOD/BARK FIRED BOILERS[a]

EMISSION FACTOR RATING: E (A for dry electrostatic granular filter [DEGF])

Particle size[b] (μm)	Cumulative mass % ≤ stated size					Cumulative emission factors [kg/Mg (lb/ton) wood/bark, as fired]				
	Uncontrolled[c]	Controlled				Uncontrolled[c]	Controlled			
		Multiple cyclone[d]	Multiple cyclone[e]	Scrubber[f]	DEGF		Multiple cyclone[d]	Multiple cyclone[e]	Scrubber[f]	DEGF[d]
15	94	96	35	98	77	3.38 (6.77)	2.88 (5.76)	0.95 (1.90)	0.216 (0.431)	0.123 (0.246)
10	90	91	32	98	74	3.24 (6.48)	2.73 (5.46)	0.86 (1.72)	0.216 (0.432)	0.118 (0.236)
6	86	80	27	98	69	3.10 (6.20)	2.40 (4.80)	0.73 (1.46)	0.216 (0.432)	0.110 (0.220)
2.5	76	54	16	98	65	2.74 (5.47)	1.62 (3.24)	0.43 (0.86)	0.216 (0.432)	0.104 (0.208)
1.25	69	30	8	96	61	2.48 (4.97)	0.90 (1.80)	0.22 (0.44)	0.211 (0.422)	0.098 (0.196)
1.00	67	24	6	95	58	2.41 (4.82)	0.72 (1.44)	0.16 (0.32)	0.209 (0.418)	0.093 (0.186)
0.625	-	16	3	-	51	-	0.48 (0.96)	0.081 (0.162)	-	0.082 (0.164)
TOTAL	100	100	100	100	100	3.6 (7.2)	3.0 (6.0)	2.7 (5.4)	0.22 (0.44)	0.16 (0.32)

[a] Reference 31. Dash = insufficient data.

[b] Expressed as aerodynamic equivalent diameter.

[c] From data on underfeed stokers. May also be used as size distribution for wood fired boilers.

[d] From data on spreader stokers. With fly ash reinjection.

[e] From data on spreader stokers. Without fly ash reinjection.

[f] From data on dutch ovens. Estimated control efficiency, 94%.

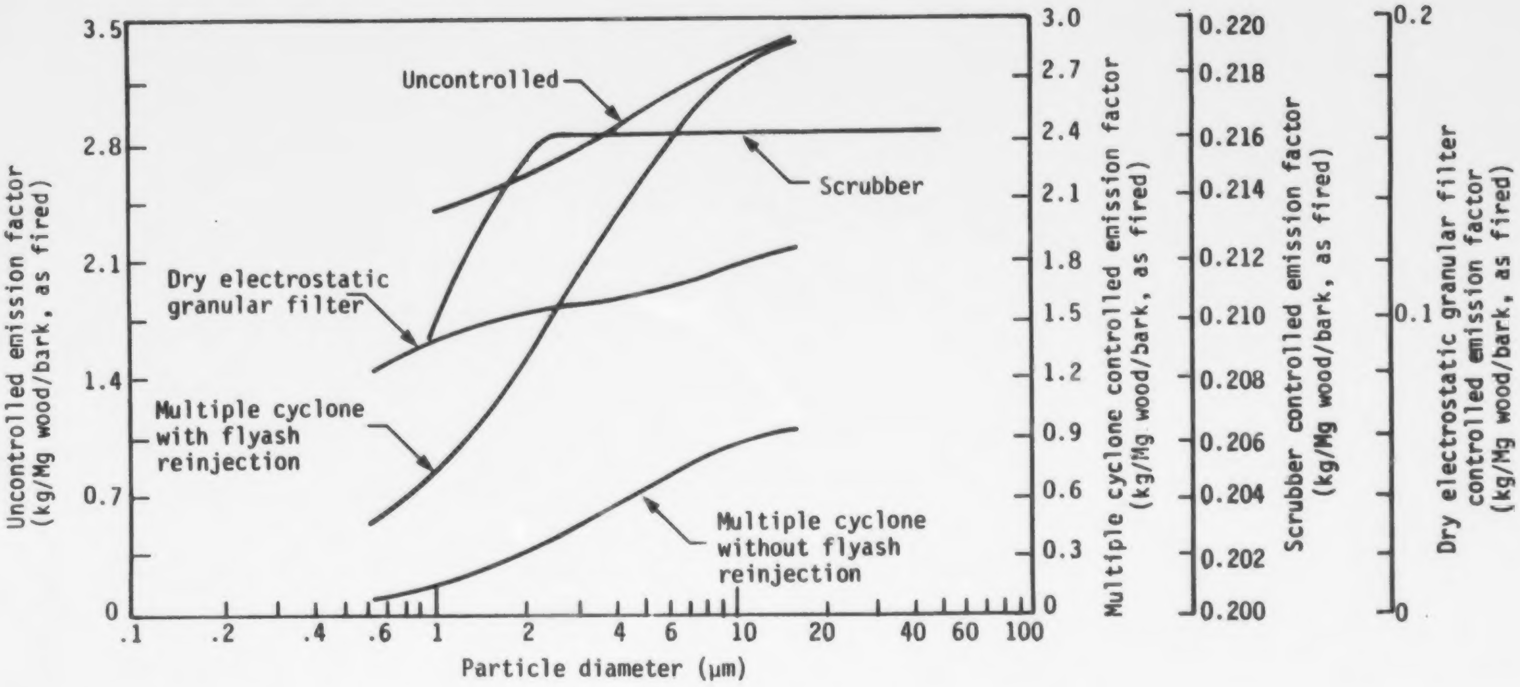

Figure 1.6-2. Cumulative size specific emission factors for wood/bark fired boilers.

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1.7 LIGNITE COMBUSTION

1.7.1 General[1-4]

Lignite is a relatively young coal with properties intermediate to those of bituminous coal and peat. It has a high moisture content (35 to 40 weight percent) and a low wet basis heating value (1500 to 1900 kilocalories) and generally is burned only near where it is mined, in some midwestern states and Texas. Although a small amount is used in industrial and domestic situations, lignite is used mainly for steam/electric production in power plants. In the past, lignite has been burned mainly in small stokers, but today the trend is toward use in much larger pulverized coal fired or cyclone fired boilers.

The major advantages of firing lignite are that, in certain geographical areas, it is plentiful, relatively low in cost and low in sulfur content (0.4 to 1 wet basis weight percent). Disadvantages are that more fuel and larger facilities are necessary to generate a unit of power than is the case with bituminous coal. The several reasons for this are (1) the higher moisture content means that more energy is lost in the gaseous products of combustion, which reduces boiler efficiency; (2) more energy is required to grind lignite to combustion specified size, especially in pulverized coal fired units; (3) greater tube spacing and additional soot blowing are required because of the higher ash fouling tendencies; and (4) because of its lower heating value, more fuel must be handled to produce a given amount of power, since lignite usually is not cleaned or dried before combustion (except for some drying in the crusher or pulverizer and during transfer to the burner). No major problems exist with the handling or combustion of lignite when its unique characteristics are taken into account.

1.7.2 Emissions And Controls[2-11]

The major pollutants from firing lignite, as with any coal, are particulate, sulfur oxides, and nitrogen oxides. Volatile organic compounds (VOC) and carbon monoxide emissions are quite low under normal operating conditions.

Particulate emission levels appear most dependent on the firing configuration in the boiler. Pulverized coal fired units and spreader stokers, which fire much or all of the lignite in suspension, emit the greatest quantity of flyash per unit of fuel burned. Cyclone furnaces, which collect much of the ash as molten slag in the furnace itself, and stokers (other than spreader), which retain a large fraction of the ash in the fuel bed, both emit less particulate matter. In general, the relatively high sodium content of lignite lowers particulate emissions by causing more of the resulting flyash to deposit on the boiler tubes. This is especially so in pulverized coal fired units wherein a high fraction of the ash is suspended in the combustion gases and can readily come into contact with the boiler surfaces.

Nitrogen oxide emissions are mainly a function of the boiler firing configuration and excess air. Stokers produce the lowest NO_x levels, mainly

TABLE 1.7-1. EMISSION FACTORS FOR EXTERNAL COMBUSTION OF LIGNITE COAL[a]

Firing configuration	Particulate[b]		Sulfur oxides[c]		Nitrogen oxides[d]		Carbon monoxide	Volatile organics	
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton		Nonmethane	Methane
Pulverized coal fired dry bottom	3.1A	6.3A	15S	30S	6[e,f]	12[e,f]	g	g	g
Cyclone furnace	3.3A	6.7A	15S	30S	8.5	17	g	g	g
Spreader stoker	3.4A	6.8A	15S	30S	3	6	g	g	g
Other stoker	1.5A	2.9A	15S	30S	3	6	g	g	g

[a] For lignite consumption as fired.

[b] References 5-6, 9, 12. A = wet basis % ash content of lignite.

[c] References 2, 5-6, 10-11. S = wet basis weight % sulfur content of lignite. For high sodium/ash lignite (Na_2O >8%), use 8.5S kg/Mg (17S lb/ton); for low sodium/ash lignite (Na_2O <2%), use 17.5S kg/Mg (35S lb/ton). If unknown, use 15S kg/Mg (30S lb/ton). The conversion of SO_2 is shown to be a function of alkali ash constituents.

[d] References 2, 5, 7-8. Expressed as NO_2.

[e] Use 7 kg/Mg (14 lb/ton) for front wall fired and horizontally opposed wall fired units, and 4 kg/Mg (8 lb/ton) for tangentially fired units.

[f] May be reduced 20 - 40% with low excess firing and/or staged combustion in front fired and opposed wall fired units and cyclones.

[g] Factors in Table 1.1-1 may be used, based on combustion similarity of lignite and bituminous coal.

because most existing units are relatively small and have lower peak flame temperatures. In most boilers, regardless of firing configuration, lower excess combustion air means lower NO_x emissions.

Sulfur oxide emissions are a function of the alkali (especially sodium) content of the lignite ash. Unlike most fossil fuel combustion, in which over 90 percent of the fuel sulfur is emitted as SO_2, a significant fraction of the sulfur in lignite reacts with the ash components during combustion and is retained in the boiler ash deposits and fly ash. Tests have shown that less than 50 percent of the available sulfur may be emitted as SO_2 when a high sodium lignite is burned, whereas more than 90 percent may be emitted from low sodium lignite. As a rough average, about 75 percent of the fuel sulfur will be emitted as SO_2, the remainder being converted to various sulfate salts.

Newer lignite fired utility boilers are equipped with large electrostatic precipitators with as high as 99.5 percent particulate control. Older and smaller electrostatic precipitators operate at about 95 percent efficiency. Older industrial and commercial units use cyclone collectors that normally achieve 60 to 80 percent collection efficiency on lignite flyash. Flue gas desulfurization systems identical to those on bituminous coal fired boilers are in current operation on several lignite fired utility boilers. (See Section 1.1).

Nitrogen oxide reductions of up to 40 percent can be achieved by changing the burner geometry, controlling excess air and making other changes in operating procedures. The techniques for bituminous and lignite coal are identical.

TABLE 1.7-2. EMISSION FACTOR RATINGS FOR LIGNITE COMBUSTION

Firing configuration	Particulate	Sulfur dioxide	Nitrogen oxides
Pulverized coal fired dry bottom	A	A	A
Cyclone furnace	C	A	A
Spreader stoker	B	B	C
Other stokers	B	C	D

TABLE 1.7-3. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR BOILERS BURNING PULVERIZED LIGNITE COAL[a]

EMISSION FACTOR RATING: E

Particle size[b] (μm)	Cumulative mass % ≤ stated size		Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[d]
15	51	77	1.58A (3.16A)	0.477A (0.954A)
10	35	67	1.09A (2.18A)	0.415A (0.830A)
6	26	57	0.81A (1.62A)	0.353A (0.706A)
2.5	10	27	0.31A (0.62A)	0.167A (0.334A)
1.25	7	16	0.22A (0.44A)	0.099A (0.198A)
1.00	6	14	0.19A (0.38A)	0.087A (0.174A)
0.625	3	8	0.09A (0.18A)	0.050A (0.100A)
TOTAL	100	100	3.1A (6.2A)	0.62A (1.24A)

[a] Reference 13.

[b] Expressed as aerodynamic equivalent diameter.

[c] A = coal ash weight % content, as fired.

[d] Estimated control efficiency for multiple cyclone, 80%.

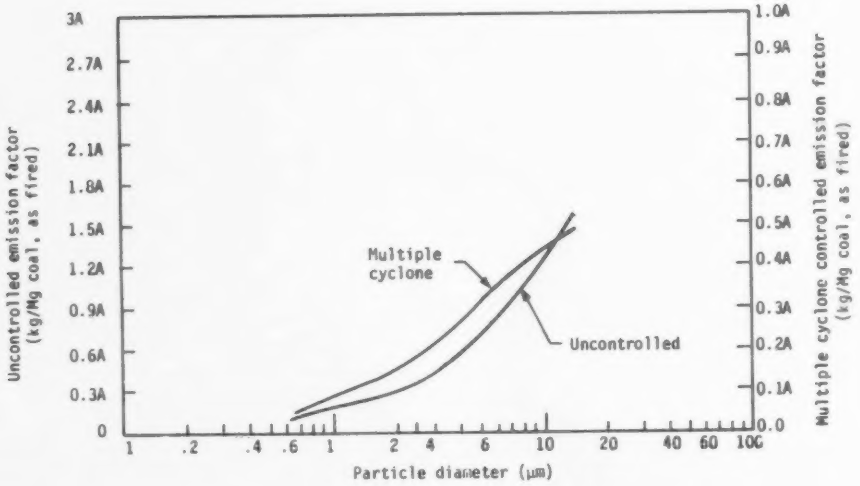

Figure 1.7-1. Cumulative size specific emission factors for boilers burning pulverized lignite coal.

TABLE 1.7-4 CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR LIGNITE FUELED SPREADER STOKERS[a]

EMISSION FACTOR RATING: E

Particle size[b] (µm)	Cumulative mass % ≤ stated size		Cumulative emission factor[c] [kg/Mg (lb/ton) coal, as fired]	
	Uncontrolled	Multiple cyclone controlled	Uncontrolled	Multiple cyclone controlled[d]
15	28	55	0.95A (1.9A)	0.374A (0.748A)
10	20	41	0.68A (1.36A)	0.279A (0.558A)
6	14	31	0.48A (0.96A)	0.211A (0.422A)
2.5	7	26	0.24A (0.48A)	0.177A (0.354A)
1.25	5	23	0.17A (0.34A)	0.156A (0.312A)
1.00	5	22	0.17A (0.34A)	0.150A (0.300A)
0.625	4	e	0.14A (0.28A)	e
TOTAL	100	100	3.4A (6.8A)	0.68A (1.36A)

[a] Reference 13.

[b] Expressed as aerodynamic equivalent diameter.

[c] Coal ash weight % content, as fired.

[d] Estimated control efficiency for multiple cyclone, 80%.

[e] Insufficient data.

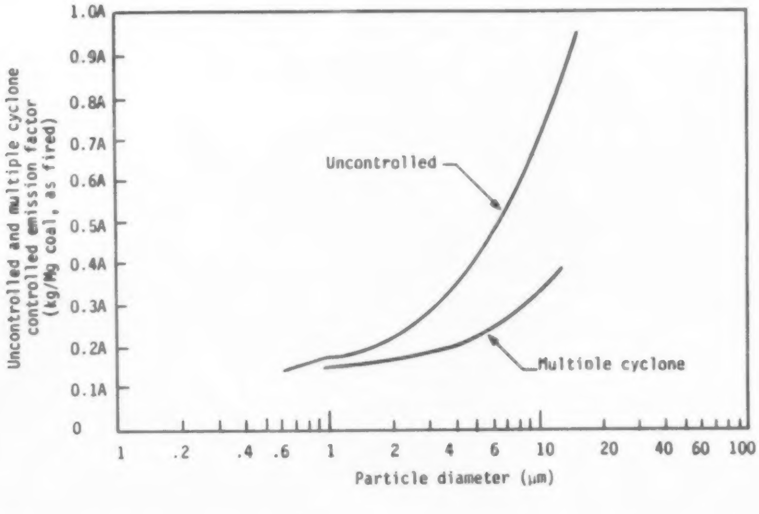

Figure 1.7-2. Cumulative size specific emission factors for lignite fueled spreader stokers.

Emission factors for particulate, sulfur dioxide and nitrogen oxides are presented in Table 1.7-1, and emission factor ratings in Table 1.7-2. Specific emission factors for particulate emissions, and emission factor ratings for the cumulative particle size distributions, are given in Tables 1.7-3 and 11.7-4. Uncontrolled and controlled size specific emission factors are presented in Figures 1.7-1 and 1.7-2. Based on the similarity of lignite combustion and bituminous coal combustion, emission factors for carbon monoxide and volatile organic compounds (Table 1.1-1), and cumulative particle size distributions for cyclone furnaces, uncontrolled spreader stokers and other stokers (Tables 1.1-5 through 1.1-8) may be used.

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APPENDIX A

GLOSSARY OF TERMS

Aerodynamic equivalent diameter:

> Diameter of a sphere of unit density that reaches the same terminal settling velocity at low particle Reynolds number in still air as the actual particle.

Cascade impactor:

> An inertial-based particle collection instrument for determining mass-based size fractions.

Inhalable particulate matter:

> Particles of respirable size and capable of reaching the lower lung, usually whose diameter is less than or equal to 15 µm.

Isokinetic sampling:

> Sampling in which the linear velocity of the gas entering the sampling nozzle is equal to that of the undisturbed gas stream at the sample point.

AAF: American Air Filter

EPA: U. S. Environmental Protection Agency

FGD: Flue gas desulfurization

ESP: Electrostatic precipitator

Mg: 10^6 grams

kg: 10^3 grams

MW: megawatts

J: joule

GJ: gigajoule

kg/s: kilograms per second

l: Liter

Mechanical collector:

> A device that separates suspended particles from a gas stream by causing the gas stream to change direction while the particles, due to their inertia, tend to continue in their original direction and be separated from the gas.

PADRE and FPEIS:

> The Particulate Data Reduction (PADRE) system is an interactive computer program that facilitates entry of validated cascade impactor data for particle size distributions from representative in-stack runs into the Fine Particle Emissions Information System (FPEIS). PADRE was developed to ensure the quality of data included in FPEIS, which is a component of the Environmental Assessment Data Systems (EADS). Impactor stage cut points are calculated and cumulative and differential mass concentrations are determined and interpolated to standard diameters. Data entered through PADRE are not automatically included in FPEIS; the test contractor should designate representative runs after data validation.
>
> Upon request, FPEIS can generate computer listings of the entered and PADRE-reduced data for each test series. One test series is normally associated with all source sampling at a tested site during a continuous period which may be less than one day to more than a week.

SASS train:

> Source Assessment Sampling System. An inertial-based system normally consisting of three cyclones and a filter in series used to obtain particulate greater than 10 μm, less than 10 μm but greater than 3 μm, less than 3 μm, but greater than 1 μm, and less than 1 μm. Organic and inorganic materials are also captured in the XAD-2 and impinger.

TVA: Tennessee Valley Authority

APPENDIX B

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